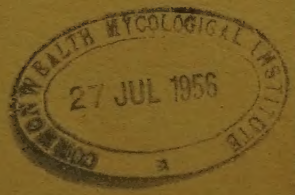
REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1955



Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

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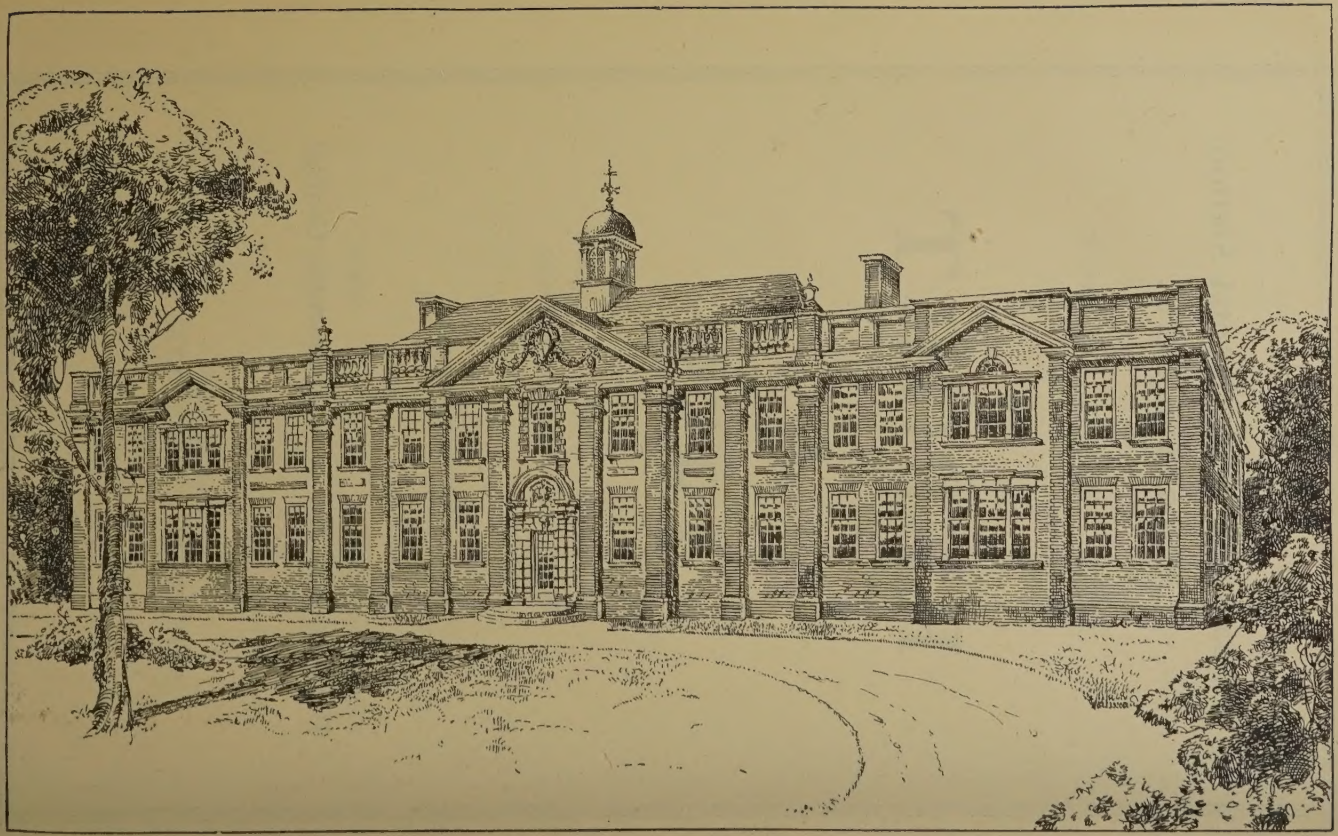

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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Soil Surveyors

G. D. Ashley, B.Sc.(Sheffield)
B. W. Avery, B.Sc.(Reading)
D. F. Ball, B.A.(Cantab.)
B. Clayden, B.Sc.(Sheffield)
C. B. Crampton, B.Sc.(Bristol)
A. Crompton, B.Sc.(Leeds)
E. Crompton, M.Sc.(Manc.)
L. F. Curtis, B.Sc.(Bristol)
D. C. Findlay, B.A.(Cantab.)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(Edin.)
J. F. Harrop, B.Sc.(Sheffield)
C. A. H. Hodge, B.Sc.(Wales)
J. H. James, Ph.D.(Bristol)
D. W. King, B.Sc.(Lond.)
D. Mackney, B.Sc.(Bristol)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
A. J. Thomasson, B.A.(Bristol)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.) (In Northern Rhodesia)
G. F. M. Murdoch, M.A.(Edin.) (In Swaziland)

Chemists

C. L. Bascomb, B.Sc.(Agric.)(Reading)
H. H. Le Riche, B.Sc.(Lond.)

Temporary Workers

J. C. Chisnell, B.Sc.(Nott.)
C. D. Ollier, B.Sc.(Bristol)
J. Stark, M.A.(Glas.)

Cartographer

D. V. Jones

Assistant Staff

R. F. Allbrook, Pamela Ash, Mrs. Audrey M. Denton-Hughes, Mrs. Joan K. Foster, M. A. Murphy, Sheila Pettitt, Mrs. Sheila M. Wright

Woburn Experimental Station

Director

Sir William G. Ogg, M.A., B.Sc., LL.D.(Aberd.), Ph.D. (Cantab.)

Assistant Director

H. H. Mann, D.Sc., F.R.I.C. (Kaisar-i-Hind Gold Medal)

Chemist

T. W. Barnes, M.Sc.(Lond.), F.R.I.C.

Assistants

A. Peacock, G. Pearce.

FARM STAFF

Head of Farms

J. R. Moffatt, B.Sc.(Agric.)(Lond.), N.D.A., A.I.B.A.E.

Assistant

G. F. Cole

Bailiff

A. W. Neill

Farm Workers

C. Hathaway, R. Holliman, Clara E. Horn, W. Hummerston, W. A. McCallum, K. Wilson, W. Wilson

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director

F. G. Gregory, D.Sc.(Lond.), F.R.S.

Head of Department

F. J. Richards, D.Sc.(Birm.), F.R.S.

Scientific Staff

E. H. Grice-Hutchinson, B.Sc.(St. And.)
C. A. Priestley, B.A.(Cantab.)
W. W. Schwabe, Ph.D.(Lond.)

Assistant Staff

W. S. Biggs, C. Sinclair, Pamela Smith

The Commonwealth Bureau of Soil Science

Director	G. V. Jacks, M.A.
Consultant Director ...	Sir W. G. Ogg, M.A., Ph.D., LL.D.
Assistant Director ...	W. D. Brind, B.Sc.
Assistants	G. A. Greenwood, B.Sc. Mrs. M. Kathleen Milne, B.Sc. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Clerks	Christine E. Dollimore, Mrs. Iris Lindsay, Marguerita D. Payne, Mrs. Rita M. Starkins

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government has been requested to nominate one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly sixty years. Lawes died in 1900, and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943, when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir. J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income from which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department. In 1946 Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research Department.

In 1947 the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted, and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

In 1940 the south wing was completed and the old chemical laboratories reconstructed. These extensions and reconstructions provide accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition, a range of pot-culture houses was built. In 1939 a laboratory was completed for workers from the Imperial College of Science and Technology. A West

Building, to house the Entomology and Insecticides Departments together with the mycologists of the Plant Pathology Department, was completed in 1955.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power; further additions were made in 1939–40. A range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but Rothamsted also gains considerably by this closer association with the universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934 the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted estate were completed. The Lawes Agricultural Trust now owns the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house and eight cottages. The total area is 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers and from oversea sources.

During 1951–52 the Manor House was converted into a Hall of Residence, providing accommodation for seven families, rooms for twenty single workers and two guest rooms. Some of the large public rooms are available for lectures and general institutional purposes. The fabric of the older part of the building, part of which dates back to the 13th century, has been carefully preserved. The greater part of the cost was met by the Ministry of Agriculture, but the Station also received encouragement and financial aid from the Pilgrim Trust. The conversion has greatly enhanced the amenities of Rothamsted, and the accommodation is particularly useful for the younger members of staff and temporary workers from overseas. An illustrated guide to the Manor with an account of its history has been published (1953) under the title *The Manor of Rothamsted*.

The activities of Rothamsted, however, are not confined to the British Isles, but are gradually reaching out to many parts of the

world. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

Rothamsted offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soil Science, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

The Library may be said to have come into being in 1913, when the Sir Henry Gilbert Collection, presented by Lady Gilbert, was added to the small body of reference works used in the Laboratory at that time—most of them the gift of Sir John Lawes himself.

Its expansion, aided by gifts and grants from a number of individuals and societies, was rapid, until it now contains :

	(Approximately)
Periodicals ... ... (Current, 1,600)	4,800
Books, 1841–	11,000
Books, 1471–1840 ... ... (including 14 incunabula)	3,500
Bound volumes of pamphlets	400
MSS.	100
Maps	300
Prints	200

—in all about 18,000 items, comprising some 53,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most-used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471–1840), which is kept separate from the rest, includes fourteen incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture —produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry*, by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this col-

lection was made in 1948, when Lord Northbrook presented to Rothamsted his father's collection of prints.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use is extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books on agriculture (Rothamsted, 1926; second edition, 1940; supplement 1949). A complete catalogue of the serial publications in the Library was published in 1954.

INTRODUCTION

By the Director

It is with deep regret that we record the deaths of Sir Alexander Fleming, a member of the Lawes Agricultural Trust Committee since 1953, and Mr. Edwin Grey, the last remaining link with our Founder. Ted Grey, as he was affectionately called, came to Rothamsted as a "grass picker" in 1872 at the age of twelve, and was on the staff for sixty-eight years. He did a variety of increasingly responsible jobs in the laboratory and on the farm, and was finally Superintendent of the experimental plots, a post he held until his retirement from full-time work in 1922. He was a remarkable character and was known to agriculturists the world over. His *Reminiscences, tales and anecdotes* of Rothamsted (1922) and *Cottage life in a Hertfordshire village* (1934) bear witness to his affection for Rothamsted and his interest in rural life.

Professor D. D. Woods has been appointed to the vacancy on the Trust Committee as a representative of the Royal Society. In June 1955 Dr. C. B. Williams, who had been Head of the Entomology Department since 1932, retired and Dr. K. Mellanby from the London School of Hygiene was appointed in his place. Dr. Williams is continuing his work on quantitative ecology at Kincraig, Inverness-shire, with the aid of a grant from the Agricultural Research Council. Dr. B. G. Peters resigned from the Headship of the Nematology Department at the end of September 1955 to become the first Professor of Parasitology at the Imperial College of Science and Technology, London. Mr. F. G. W. Jones, Lecturer in Agricultural Zoology at Cambridge University, has been appointed to succeed him, and will take up his duties in January 1956. Dr. R. K. Schofield, who has been on the staff since 1928 and has been Head of the Chemistry Department since 1954, has been appointed Reader in Soil Science at Oxford University.

Dr. L. Broadbent was awarded a Kellogg Scholarship and spent three months visiting universities and research stations in the United States and Canada, and Dr. Mary T. Franklin also spent four months in the United States and Canada, working mainly at the Connecticut Agricultural Experiment Station, New Haven. Mr. M. V. Tracey obtained a Royal Society and Nuffield Foundation Commonwealth Bursary and will spend a year at the Wool Textile Laboratory of the Commonwealth Scientific and Industrial Research Organization at Melbourne. Dr. A. W. Taylor returned from the University of Wisconsin, where he had held a post-doctorate fellowship, and Dr. P. W. Murphy resumed his work in the Entomology Department after spending a year at the University of Vienna. Dr. T. W. Tinsley returned from the West African Cocoa Research Institute, Tafo, Gold Coast, where Miss Margaret Holden and Dr. F. Raw are still on secondment.

Sir William Ogg visited Finland at the invitation of the University of Helsinki and the British Council to give lectures and visit agricultural and forestry research organizations. He also accepted invitations to take part in a Round Table Conference at the Swedish

Royal Academy of Agriculture and to lecture at the Royal Agricultural College, Uppsala. Mr. F. C. Bawden went to West Africa to advise on swollen shoot disease of cocoa, and Dr. H. L. Penman visited the Gold Coast at the invitation of the Volta River Project Preparatory Commission. Dr. H. Greene, Adviser on Tropical Soils, went overseas on three occasions during the year, visiting West Africa, the United States, the High Commission territories of Swaziland and Basutoland, and the Sudan. These visits were concerned with soil surveys, field experiments, UNESCO's work on arid regions and various other problems. Dr. A. Muir was a member of the British Agricultural Delegation to the U.S.S.R.; and on behalf of the European Productivity Agency of the Organization for European Economic Co-operation Dr. G. W. Cooke visited research institutes in Denmark, Norway and Sweden. Mr. H. V. Garner spent three weeks studying field experimental methods in Holland, West Germany and Denmark, and Dr. N. Walker accepted the invitation of Professor E. B. Chain to work for six weeks at the International Centre for Research in Chemical Microbiology in Rome.

Rothamsted was represented at the 3rd International Congress of Biochemistry in Brussels, a Conference of Agricultural Physicists in Wageningen and the International Symposium on Plant Nematodes in Wageningen. Mr. F. C. Bawden attended a meeting in Paris of a study group " to consider how UNESCO might help to promote knowledge on cell growth with a view to assisting research on cancer ". Dr. G. W. Cooke contributed a paper to the meeting of the Association Internationale d'Études Phosphatières held in Blois, France, and Dr. C. G. Johnson to the German Plant Protection Conference at Kassel. Mr. N. W. Pirie attended the World Symposium on Applied Solar Energy in Arizona, and Mr. D. H. Boalch the meetings of the International Congress of Agricultural Librarians and Documentalists in Frankfurt and Ghent. Dr. R. Hull and Mr. H. V. Garner both attended meetings of the International Institute of Sugar Beet Research.

Mr. F. C. Bawden was the first recipient of the Royal Agricultural Society of England's Research Medal in recognition of his work on virus diseases of crops. Sir William Ogg retired from the Presidency of the Society of Chemical Industry in July; he delivered the 9th Dalton Lecture in Manchester on 28 October. Dr. H. G. Thornton has been appointed Foreign Secretary of the Royal Society.

Visitors

There were over 3,500 visitors to Rothamsted during the year, many from overseas. In July H.R.H. the Duke of Gloucester paid an informal visit, accompanied by Mr. F. Wycherley, his agent at Barnwell. The Marquess of Salisbury, Lord President of the Council, Mr. D. Heathcoat Amory, M.P., the Minister of Agriculture, Fisheries and Food, and Lord St. Aldwyn and Mr. G. H. R. Nugent, Joint Parliamentary Secretaries also visited the Station. Visitors from overseas included Mr. Ezra T. Benson, United States Secretary of Agriculture, and Mrs. Benson; Mr. Jens Smørum, Danish Minister of Agriculture; Mr. J. Dillon, T.D., the Irish Minister of Agriculture, and the Irish Ambassador, Mr. H. F. Boland; Mr.

J. E. Jantuah, Minister of Agriculture for the Gold Coast; Dr. Eric Englund, United States Agricultural Attaché, and Mrs. Englund; Mr. K. R. Damle, Vice-President of the Indian Council of Agricultural Research, and senior Indian Government officials. Visitors from the U.S.S.R. included Mr. I. Benediktov, Minister of State Farms; Academician Tsitsin, Director of the Moscow Agricultural Exhibition; Academician I. G. Petrovsky, Rector of Moscow University; and Academician A. L. Kursanov, Director of the Timiryazev Institute of Plant Physiology.

Buildings and Land

The West Building was completed in the spring, and the Entomology, Insecticides and Fungicides Departments and the mycologists of the Plant Pathology Department have moved into their new accommodation. The space vacated by the Entomology Department at Rothamsted Lodge has provided more room for the Bee Department and the Bee Advisory Service; the old Insecticides laboratories are being used by the Botany Department and the Office.

Two orchards adjoining the north boundary of the farm, together amounting to 26 acres, were purchased during the year. The trees were in very poor condition and, apart from a small area, are being grubbed up. The land, which is to be known as Whittlocks, will be used for experimental purposes.

The Work of the Station

In the **Physics** Department much attention continues to be given to the question of soil structure. This is dependent on the surface physics of the mineral components, particularly of the clays, and careful work on one clay, kaolin, has shown almost conclusively that there are charges on the edges of the kaolin crystals in addition to the isomorphous replacement charges associated with the basal surfaces. There are indications that the action of some soil conditioners such as polyacrilic acid is due to the edge-to-edge linking of the clay crystals, whereas linking of the basal surfaces in interlamellar complexes may be the dominant factor in the crumb structure built up under a grass ley. Field experiments have provided some evidence that improved crumb structure increases crop yields.

The environment of the growing plant has a direct bearing on the incidence of diseases. Studies of dew formation and persistence on potato plants (an important aspect of the blight problem) have made progress, and equipment is now almost complete for a comprehensive experiment on potatoes in which daytime transpiration and night-time condensation will be continuously measured at the same time as the energy transfer in and above the soil. Work has also been started on the micro-meteorological problems of cereals; the first year's pilot experiment has revealed significant differences between close and open stands of wheat. Little control of environment is possible except that deficiencies of rainfall may be made good by irrigation. The dry weather from mid-June onwards has indicated how much benefit may be derived from such control, for the irrigation experiment has shown a 60 per cent increase in dry

matter from irrigated grass, 90 per cent from main crop potatoes (from 11 tons/acre without irrigation to 20½ tons with 6 inches irrigation) and 40 per cent in sugar yield from sugar beet.

The **Chemistry** Department's work on fertilizer placement has been continued. Placing of both superphosphate and muriate of potash increased yields of peas and beans on soils where broadcasting these fertilizers had little effect. On ordinary potassium-deficient soils combine-drilling muriate of potash gave higher yields of barley than twice as much broadcast potash, confirming the results of earlier work on Chalk soils. For potatoes, placing potash beside the seed gave consistently higher yields than broadcasting. In contrast, placing and broadcasting of nitrogen fertilizers gave similar yields for both cereals and potatoes. Experiments carried out over the last three years show that there is no gain from splitting the normal nitrogen dressing used for main crop potatoes, higher yields being obtained by applying all the nitrogen before planting than by applying a portion of it before earthing-up the potatoes. In a comparison of calcium nitrate with ammonium sulphate, the two forms of nitrogen gave similar yields of cereals and of kale; for potatoes calcium nitrate was inferior, particularly when heavy dressings were used. Work on nitrogen for spring cereals emphasizes the difficulties of recommending the " best " rates, and times and methods of application, since so much depends on soil and weather conditions. For the present it seems best to suggest that nitrogen dressings for spring corn should be split, part being given to the seedbed and the remainder applied as a top-dressing in May. In ten long-term experiments on oil palms carried out in West Africa, potassium fertilizers consistently increased yields; phosphorus was effective on only one kind of soil, and there were no gains from dressings of nitrogen, calcium or magnesium. In examining these data it was necessary to take account of both climatic cycles and physiological rhythms in the crop. In the investigation on the manuring of forest nurseries copper sprays cured a deficiency-symptom described as " needle-tipburn " of Sitka spruce seedlings which had appeared on plots on a heathland soil. On plots where a hop-waste compost was used there was no deficiency, since the compost contained an appreciable amount of copper. In pot experiments the yields of oats grown on a calcareous " skirt " fen soil were increased by both complex and simple salts of manganese, although symptoms of " greyspeck " disease were not completely eliminated.

Estimates of the values of dicalcium phosphate and rock phosphate, in terms of superphosphate as standard, have been made in pot and field experiments by measuring both crop yields and phosphorus contents and also by using radio-tracer techniques. Isotopic exchange is being used to examine the phosphorus status of soils which have had varying manurial histories. Important progress has been made in defining the conditions under which denitrification occurs in soils, particular attention being given to the losses of nitrogen which are promoted by additions of organic materials. Studies on the nature of organic phosphorus compounds present in soils have continued.

In the **Pedology** Department mineralogical studies have been carried out on a wide range of soils and soil clays from this country

and from various parts of Africa. It would appear that the black clay soils from the Athi Plains, Kenya, show microreliefs similar to those of Australian gilgai soils. An examination of the calcareous shales of the Lower Lias formation has shown that there are high concentrations of molybdenum in the lower zones and in shales with between 10 and 50 per cent calcium carbonate. In an investigation of the trace element content of crops from the classical plots it was found that wheat shoots from Broadbalk field showed little variation from plot to plot. Where continued application of ammonium sulphate has increased soil acidity, however, the molybdenum content was strongly depressed. Determination of the inorganic constituents of cocksfoot from Park Grass field, when the plants were in flower (June), showed little variation in the Ca content of non-flowering shoots between limed and unlimed plots. Copper uptake followed the pH of the various plots with the lowest value on a limed area. Molybdenum uptake increased with pH, but the content seems to be influenced positively by the dung and guano treatment on a no-lime plot. Further studies have been made of the effect of materials leached out of leaves on the mobility of sesquioxides and clay with reference to movement in soils.

The **Soil Microbiology** Department has commenced a study of the non-symbiotic nitrogen-fixing organisms in Broadbalk field. It would appear that the anaerobic *Clostridium pasteurianum* is much more abundant than Azotobacter and may be of more importance in nitrogen fixation.

Further work has been done on the breakdown of herbicides in soil, and organisms that can decompose 2 : 4-D, MCPA and parachlorophenoxyacetic acid have been isolated and are being studied. Treatment of soil with any of these compounds accelerates the rate of decomposition of the compound added, or of the other two. As small an addition as 1 part per million of 2 : 4-D will thus adapt the soil to its decomposition. A soil adapted to decompose 2 : 4-D or MCPA will retain this adaptation for at least 6 months.

A survey has been made of the types of predominant fungi in clover rhizospheres in the surrounding soils. Preliminary results show some differences in numbers and types of fungi, both as between rhizospheres and surrounding soil and between clover-sick and healthy soil. Experiments have been carried out to test growth and survival of clover nodule organisms in soil and in media at various pH. In sterilized soil at a pH below 5·7 none grew and all died within two weeks. Work has shown that on the introduction of effective strains a ratio of 1 : 1,000 of a competitive ineffective strain was sufficient to give improved clover growth, and higher ratios gave an increased effect.

The **Botany** Department is working on certain aspects of plant nutrition, weed problems, the physiological effects of virus infection and the physiological limitations of crop yield. It has been found that molybdenum added to a complete nutrient solution delayed the precipitation of iron, possibly because it also retarded the upward drift of pH. This may account for the increased uptake of iron and the reduction of chlorosis when molybdenum is supplied to plants growing with a deficiency of iron. The interaction between molybdenum and iron may be at least partly due to chemical reaction outside the plant.

The application to wheat of a nitrogenous spring top-dressing in the same spray solution as 2 : 4-D has been studied, and it appears that the weed-killing effect was not interfered with, but only about half as much nitrogen was recovered in the crop as when it was applied as fertilizer to the soil.

The studies of wild oats and of certain other weeds have been continued, and it has been found possible to reduce the amount of viable seed produced by wild oats by spraying them with maleic hydrazide after the panicles emerge; but this is not a practical measure, as the crop may also be severely damaged. There are indications that the population of viable wild oat seeds rapidly decreases under temporary ley.

In the **Biochemistry** Department most attention continues to be given to the study of enzymes. Three of these, ribonuclease, metaphosphatase and phosphatase, are concerned with breaking a link between a phosphate group and some other structure, and are of particular interest because of the importance of nucleic acids and phosphate esters in the metabolism of the leaf. Leaf ribonuclease preparations can now be made in which no other enzyme activity has been recognized. Work has continued on the enzymes of bracken, particularly on thiaminase, which destroys vitamin B and is in part responsible for the toxicity of bracken; furthermore, it is found in few other plants, and an attack on it might provide the basis of a selective poison for bracken. More evidence has been accumulated about the parts that amine oxidase and peroxidase may play in alkaloid formation and in controlling the concentration of growth hormone. Chitinase and related enzymes should be useful in studying the nature of fungal mycelia and their residues in soil organic matter; some strains of bacteria are promising sources of these enzymes.

The physiological state of a leaf has a great effect on its composition and on its susceptibility to virus infection, and attempts are being made to find some correlation between them. The properties of highly purified virus preparations may differ from those of viruses in the natural state in infected leaves, and the changes which take place in tobacco mosaic virus during purification are being studied.

Further progress has been made in the large-scale preparation of leaf protein. A palatable protein curd is now being produced as a first step to a product that can be stored without refrigeration.

In the **Plant Pathology** Department virus diseases are being studied in a wide range of crops, including potatoes, sugar beet, barley, and various legumes and crucifers. Potato paracrinkle virus, which is universal in the variety King Edward, seems to be an aberrant strain of potato virus S, which occurs in many other potato varieties. By excising apical meristems from King Edward plants and culturing them on agar, a clone of this variety has been established that seems to be free from paracrinkle virus. Potato virus C, although a strain of the common aphid-transmitted potato virus Y, is not transmitted by aphids when obtained directly from infected potato plants. An isolate that has been maintained for years in tobacco plants under glass has, however, become transmissible by aphids, but when transmitted to potato and returned to tobacco this isolate usually lost its ability to be transmitted by aphids.

Further attention has been given to the possibility of checking

the spread of virus diseases by means of insecticides. Spraying potato crops with DDT emulsion again prevented the spread of leaf roll within crops, but only slightly decreased the spread of rugose mosaic. This insecticide was valueless against aphids on sugar beet; other insecticides decreased the incidence of yellows, but the disease was not prevalent enough for spraying to give profitable returns. A survey showed that wild beet is abundant on many parts of the east coast and is generally infected with viruses and downy mildew fungus as well as being infested with mangold fly. The plants were free from aphids in the summer, but there was evidence at a few sites that wild beet had provided sources of pests and diseases for nearby beet or mangold crops. Wild beet now occurs on waste land and in hedges far inland up to the high-water level reached by the sea floods in 1953.

Among the diseases being studied by the mycologists are foot-rots of cereals, potato blight, potato skin spot, downy mildew of sugar beet, pea wilt and apple scab. Outbreaks of apple scab in East Anglia were again correlated with spring weather that liberated ascospores from dead leaves. The liberation of ascospores was much decreased by spraying dead leaves with DNOC. Eyespot and take-all of cereals were unusually prevalent, and in an experiment where these diseases were controlled the wheat variety Capelle, grown after potatoes, yielded up to 65½ cwt./acre, a record for Rothamsted. Further work has been done on the effects of ultra-violet radiation on plant pathogens.

Work has been continued in the **Nematology** Department on various species of eelworm of economic importance. Attention is being paid to the structure and development of cyst-forming nematodes. The detailed development of the cabbage-root eelworm appears to be very similar to that of the sugar-beet eelworm. Population studies on the cereal-root eelworm indicate that build-up appears to be more rapid on oats than on other cereals, and that in the absence of hosts there is a rapid decline in population. The study of the emergence of larvae has been extended to the cabbage-root eelworm and its responses to root diffusates investigated. The relationship of eelworms to their host plants is being studied, and a number of varieties of oats, barley and wheat have been tested for resistance to cereal-root eelworm, but no marked resistance was detected. Work on the physiology of plant nematodes has been commenced, using potato-root eelworm as material, and a start has also been made on the study of nematode parasites of insects.

In the **Insecticides** Department recent work has led to a much greater understanding of the reasons why a change in particle size of a contact insecticide produces a change in its toxicity. The effects of temperature on this change in toxicity have been studied in detail, and a theory has been put forward which may sometimes enable the effect of temperature on the relative toxicity of different-sized particles to be predicted.

The earlier work on the mode of action of organo-phosphorus compounds is being followed up. These insecticides are believed to act by inhibiting esterases, but it is not certain which of these enzymes are directly concerned with the death of the insect. Progress has been made in isolating from the German cockroach those enzymes which hydrolyse acetyl choline from those that hydrolyse

phenyl acetate but not acetyl choline. This separation is a necessary preliminary to the identification and characterization of the particular enzyme system concerned with the death of the insect.

The study of pyrethrins and allied molecules has been continued, and various substances have been synthesized and tested biologically, but it is doubtful whether they could be produced cheaply enough to compete with the natural products or the synthetic materials already in the market. Further field studies on the control of black aphis (*Aphis fabae*) on field beans and of wheat-bulb fly have been carried out, and in conjunction with the Plant Pathology Department additional information has been obtained on the prevention of virus spread through control of the aphid vectors by insecticides.

A beginning has been made with fungicide investigations. A technique for studying fungicidal action on plant pathogens has been elaborated in which the ability of treated spores not only to germinate but also to infect is measured. Work on the action of the systemic fungicide griseofulvin on club-root of cabbage and powdery mildew of cereals has been carried out, and a considerable amount of information has been obtained about the way in which this chemical affects these diseases.

Much of the work of the **Entomology** Department has continued to deal with insect numbers. Estimations of numbers of various species, and of their activity, have been made with light traps, suction traps working at different levels up to 1,000 feet above the ground, and among vegetation. Populations have also been measured in soils of various kinds, and in different crops. The results obtained have been related to changes in the weather and to variations in the physiology of the individuals concerned. This work is fundamental to any understanding and prediction of attacks by insects of economic importance, and the significance of data collected over many years is only now becoming apparent.

While some of the work has concerned insects generally, and has not been related to pest species, most of the investigations have concentrated on insects of economic importance. Gall midges attacking wheat and other crops have been studied. On Broadbalk the wheat-blossom midge has been estimated for the twenty-ninth successive year; 1955 showed a much increased infestation over 1954, with some 27,000 larvae per 500 ears of wheat. Work on the Hessian fly and on the gall midges affecting seed production in clover has been continued. Aerial trapping work has been largely concerned with aphids, whose flight-physiology has also been investigated. Soil studies relate particularly to wireworms and other beetles which attack growing crops, as well as to the relations between earthworms and fertility. Several members of the department have worked on different aspects of the life history of the wheat-bulb fly.

In the **Bee** Department much attention continues to be given to various aspects of bee behaviour. Evidence has been obtained which supports the view that food-sharing amongst the adult bees provides the network of communication which is the basis of social life in honey-bee communities, and it has recently been shown that a most important function of food sharing is the widespread and rapid distribution of " queen substance ". This material inhibits ovary development in workers and the production of queen cells;

a similar ovary-inhibiting substance appears to be present in certain other arthropods. Studies of the stimuli which lead to food exchange between worker bees indicate that scent is highly important. The accuracy with which bees communicate the whereabouts of food crops to fellow members of their colonies and the practical problems involved in inducing bees to forage on selected crops requiring pollination are also being investigated. Further information has been obtained on the factors affecting the incidence of swarming. It would appear that queen-cell production is not a reliable index, particularly after midsummer.

The researches on bee behaviour, physiology and pathology are now being applied to the solution of practical problems, such as the control of various diseases, the prevention of spoilage of stored combs by wax-moths, the introduction of queen bees and other aspects of colony management. Nosema and amoeba diseases can be eliminated from colonies by transferring the bees in early summer to combs that have been sterilized with the vapour of acetic acid. Further work has been done on European Foul Brood and on the organisms responsible for this disease.

An increasing amount of work on the design and analysis of field and laboratory experiments has been undertaken by the **Statistics** Department for Rothamsted and other research stations and for the National Agricultural Advisory Service. The electronic computer is proving very useful in this connection, and about 850 analyses of sets of experimental results, mainly randomized blocks and Latin squares, were carried out on it during the year. Good progress has also been made on the application of the machine to other branches of statistical work, and arrangements have been concluded with the National Research Development Corporation for it to remain at Rothamsted for a further period of five years. Surveys of fertilizer practice were carried out in four more districts, and a summary of the manuring of cereal crops, based on information from the fertilizer surveys, has been published. More than a third of the cereal acreage in England and Wales receives no nitrogen fertilizers, and the average dressings given are only about half the calculated optimal dressing. The conclusion is reached that profitable increases in nitrogen might increase total cereal yields by about 6 per cent. Average potash dressings on cereals are about optimal, but too much phosphate is used on much of the acreage. Contrary to current advice, as much as a third of the nitrogen used on winter cereals is applied in the seedbed in autumn, and use of complete fertilizers results in the wasteful application of phosphate and potash in spring top-dressings. Other publications include a report on the results of a survey of progress under the Hill Farm and Livestock Rearing Acts, a paper on the use of weed-killers and insecticides, and a report on the results of the 1954 Survey of rabbit damage to winter cereals. In co-operation with the National Institute for Research in Dairying and the Advisory Bacteriologists of the National Agricultural Advisory Service, a series of trials has been carried out to compare the standard hypochlorite disinfectant with some new detergent sterilizers, and in another investigation an analysis has been made of a large experimental assay of new tuberculins on cattle and tests of their powers to discriminate between tuberculous and tubercle-free cattle.

The **Field Experiments** Section and Farm staffs were responsible for 3,000 experimental plots at Rothamsted and Woburn, about 850 microplots being laid out by the scientific departments. A small area of continuous wheat has been re-established on Broadbalk; the remainder of the field will continue to have one year fallow in five. Included in this report is an account covering the 20 years 1935–54 of the effects of the fallowing system on yield, the residual effects of one year's bare fallow, the relationship of fallow to the level of fertility of the land and the effect of bare fallowing on the incidence of eyespot, take-all and wheat-bulb fly. The report also gives a condensed summary of the very large amount of detailed work carried out by the Botany Department on the effect of the fallowing system on the weed population. Much thought has recently been given to re-casting the long-term experiments which have completed their cycles. The four-course has now commenced a new period with a modified rotation and some new treatments suggested by the results of the earlier period. A new plan is under consideration for the utilization of the Agdell plots, which are meantime being cropped with nitrogen only, after the acid areas had been limed. The deep-cultivation rotation experiment will be discontinued as each block completes two entire cycles. Important modifications have been carried into the ley–arable rotation experiments to reduce eyespot disease and to equalize the status of soil potash which was being affected by differences in the management of the leys. The most notable addition to the annual experiments has been a new series of experiments at Rothamsted and Woburn to investigate the nitrogenous manuring of spring wheat, including rates of application of "Nitro-Chalk", different times of application and a study of divided dressings.

At Woburn the dry summer was favourable for cereal crops, but main crop potatoes and grass only gave full yields under irrigation. The permanent barley plots each received a dressing of ground chalk sufficient to raise the pH to 6·0. The crop was much improved by the chalking, and the land will now be intensively cleaned in 1956. The ley–arable experiment, now in its eighteenth season, has shown the value of leys on the Woburn soil, but the results are now being complicated by the potato-root eelworm, which has built up, particularly in the purely arable rotations. This will necessitate a modification in the experiment. Observations have been made to ascertain the factors involved in the increase in yield observed in spring-sown wheat and barley following the application of "Nitro-Chalk". Preliminary results indicate that the ear length of barley increases in proportion to the nitrogen applied, but the effect in increasing the numbers of ears per foot of row falls off rapidly as the dressing is increased. The effect of bulky organic manures in increasing weeds has been studied in the market-garden experiment. In general, all the organics tested increased the weeds by about one-third, whether used in single or double dressings. Work on exotic crops was continued. Maize ripened perfectly in 1955, but yields were light, two early Dutch types giving 25–30 cwt. grain/acre. The mean yields of Wisconsin and Dutch types grown for seven seasons on ordinary farm land with at most 3 cwt. sulphate of ammonia has been 35 cwt. grain/acre. The outlook for soya beans in this country is not promising, the experiments showing that only

the dwarf types ripen and that these are uncertain and not highly productive. The " Topine " strain of Jerusalem artichoke stood up well to the drought, the tops alone in 1955 giving 2·82 tons of dry matter. A study of the rate at which added organic matter disappears from Woburn soil has been completed.

PHYSICS DEPARTMENT

H. L. Penman

On his return from the University of Wisconsin, A. W. Taylor was transferred to the Chemistry Department, so leaving another gap in the establishment strength of the Physics Department. Mr. P. B. Flegg and Miss I. Warman left in April. Mr. M. A. E. G. Frère, from Louvain, spent two months with us before taking up micrometeorological research in the Belgian Congo. Professor J. A. Toogood, from the University of Alberta, came in September on sabbatic leave. Miss Margaret Dettman, from the University of Melbourne, has joined the department for a period of a year or two to assist W. W. Emerson in his soil structure studies. Mr. A. J. Wehrli, of the Technical High School, Zürich, spent two months working on soil structure. W. C. Game was given a suitably inscribed barometer by the Meteorological Office in appreciation of his services as Observer since 1911. J. S. G. McCulloch and J. L. Monteith received the Ph.D. degree of London University.

R. K. Schofield, J. L. Monteith and H. L. Penman attended the seven-day conference of agricultural physicists in Wageningen. At the invitation of the Volta River Project Preparatory Commission, H. L. Penman spent two weeks in the Gold Coast collecting local data as a basis for advice on evaporation problems that will arise if the new Lake Volta is created. During this period visits were paid to the Gold Coast University Department of Agriculture and its experimental farm, to a pilot irrigation scheme and to the Cocoa Research Institute at Tafo.

Soil Physics

There is a wide range of problems in the study of soil structure. First, and most difficult because of the heterogeneity of the material, there is the problem of the surface physics of the clay minerals; then there is the problem of the forces and compounds that can act as binding agents in aggregate formation, and the mechanisms of binding; there is the problem of testing in a reproducible way that will give a quantitative measure of "structure"; and beyond all is the problem of deciding whether there is any agricultural benefit from improved soil structure.

Electrical charges on clay (G. H. Cashen)

The intensive work on kaolin described in *Rep. Rothamst. exp. Sta. for 1953, 1954* has been continued to obtain further evidence of buffer action by the edge faces of kaolin crystals, i.e., to demonstrate the existence of positively and negatively charged edges in acid and alkaline conditions respectively. It is established that there are changes with pH of the charge carried by kaolin, but in spite of every care in the pre-treatment to "clean" the kaolin, it has not hitherto been possible to state definitely that the changes are due solely to buffer action by the edges. A method has now been

found for measuring the charge on the cleavage faces by observing the electro-osmotic movement of water in samples of kaolin treated with increasing amounts of cetyl trimethyl ammonium bromide. The cleavage faces can be made positive, which shows that this organic cation does not move when the direct-current voltage is applied: consequently the ion must be held on the surface by specific forces—hydrogen bonds—in addition to the purely electrostatic force. Measurement of the amount of CTAB necessary to reduce the charge on the cleavage faces to zero over a range of pH thus gives a new type of titration curve. Ideally the test condition should be with the cleavage faces oriented parallel to the electric field if the side edges are not to contribute to the endosmotic movement of the water: to a very good first approximation the ideal is realized, because of the intense drying which takes place as the water moves to the electrodes.

Results have been very encouraging. For a pre-treated kaolin (washed with normal KCl at pH 3, followed by normal KCl and distilled water) the charge measured with the CTAB is constant to $\pm 0{\cdot}1$ m.e. in the pH range 4·5–10. This charge must be the negative isomorphous replacement charge. For such pre-treated samples the buffering observed in earlier experiments can be more confidently attributed to the edge faces of the kaolin crystals. In contrast, for an untreated Merck kaolin the amount of CTAB required to make the kaolin positive does change with pH, an effect most probably due to the presence of some "impurity" as yet unidentified.

Soil structure (W. W. Emerson)

Synthetic soil conditioners

Sodium-saturated clay flakes have been prepared from three pure clays (a montmorillonite, an illite and a kaolinite) and a range of polymers. The swelling pattern of the flakes has been studied in dilute salt solutions, and G. C. Dibley and R. Greene-Kelly of the Pedology Department have kindly taken X-ray photographs of some of the montmorillonite complexes.

It has been deduced that the polymers can stabilize clays in two ways. First there are inter-lamellar complexes in which the polymer links the basal surfaces of the clay crystals; this can be achieved by non-ionic polymers such as poly-vinyl alcohol, or by polymers containing both anionic and cationic groups, such as gelatin. Second, there are peripheral complexes, the polymer linking the edges of the clay crystals; up to the present only cationic polymers such as carboxymethyl cellulose, alginic acid and polyacrylic acid have shown this behaviour, and the interpretation of the mechanism depends on the existence of edge charges of the kind being studied by G. H. Cashen.

The two types of complex differ in their responses to leaching with a strong solution of neutral pyro-phosphate. The wet strength of inter-lamellar complexes is unaffected, but that of the peripheral complexes is reduced to that of the clay without polymer. Dilute alkali will disperse the ionic interlamellar complexes after prolonged soaking, but polyvinyl alcohol complexes are unaffected by concentrations up to 4*N*–NaOH.

Similar experiments on the wet strength of crumbs from Rothamsted grassland showed no change on leaching with *M*/10-pyrophosphate but a very great reduction after leaching for one week with alkali. It is inferred that the grassland soil crumbs are stabilized by the formation of interlamellar complexes and that the active agents are polymers containing positively charged groups, probably amino groups.

Sodium saturation test

This technique for determining the wet strength of soil crumbs (*Rep. Rothamst. exp. Sta for 1953*) is not yet suitable for all routine measurements. It has been found that crumbs of near minimum strength are partly dispersed in 20 m*N*–NaCl, leading to blocking of pores in the sintered glass supporting the crumb bed. The permeability measurements have thus been made non-reproducible, and a modification of technique is being sought to avoid the difficulty.

Soil structure field experiment

A second set of four-year-old grass and lucerne plots was ploughed up in autumn 1954 : these and two fallow plots were later sown with spring beans. After soil analysis, appropriate nitrogen and potash fertilizer treatments were applied to plots, or part plots, to permit some discrimination between the effects of nutrients and the effects of soil structure. Unfortunately the crop was not sprayed, and grain yields were low. The appearance of the crop suggested that suspicions about last year's result were well founded : the 1953/54 differences were primarily reactions to fertilizer differences. The 1954/55 mean yield on the former fallow plots was 12·7 cwt./acre, with no response to additional N or K : the mean yield on the former ley plots was 14·7 cwt./acre. The increase of 2 cwt./acre is attributed to improved soil structure.

The first set of plots (beans in 1954) had winter wheat as a second crop, and was given a heavy dressing of a complete fertilizer to minimize differences in nutrient status. Former grass and fallow plots gave almost the same mean yield of 38 cwt. grain/acre : the former lucerne plots gave an extra yield of 5 cwt./acre.

Agricultural Meteorology

Micro-meteorology

(a) *Continuous recording* (I. F. Long)

The apparatus for continuous recording of temperature, humidity and wind-speed profiles in a potato crop has been used throughout the summer. The second set of equipment, originally intended for use on the irrigation experiment at Woburn, has been used instead on a wheat crop alongside the potatoes. Analysis of the great bulk of data now accumulated has started, and a useful preliminary operation has been the drawing up of a special set of tables and nomographs for rapid conversion of chart readings into relevant physical parameters.

New measuring equipment has been designed, made and used. An instrument for continuous recording of dew-point gradients employs nickel resistance thermometers of small dimensions. The

design exploits the approximate relationship: dew-point temperature $\simeq 2 \times$ wet-bulb temperature — dry-bulb temperature, known to be correct within $\pm 2{\cdot}5$ per cent in the temperature and humidity ranges in which it is used in night-time studies of dew formation on potatoes. The records show with acceptable accuracy the times of start and finish of dew formation, and can be used to estimate an order of magnitude of rate of condensation. This is the kind of information needed in the study of potato blight. Similar, but much smaller, nickel thermometers (1 mm. diameter and 5 mm. long) have been constructed to record leaf temperatures at two levels in a potato crop; and also for measurement of soil surface temperatures. First results indicate that in the sun leaves may be 10° C. warmer than the air round them, and on clear nights may be 2° C. colder in calm air. Leaf temperatures can change rapidly, and several times a rise and fall of 5° C. or more has occurred in 10 minutes.

Field conditions of dry soil in late summer have provided a strong contrast with previous years. Such dew formation as there has been on potatoes has come from the air rather than the soil, and there are indications that some of the water on potato leaves after a "dew" night may have been exuded by the leaves themselves. The new field observations on wheat have given a comparison of a thick (normal) crop and a thin (hand-pulled to 25 per cent normal) crop. Marked differences in temperature and humidity gradients occur—as expected—on sunny days and clear nights.

(b) *Short-period experiments* (J. L. Monteith)

Work has been concentrated on instruments to measure the components in the energy balance sheet of a crop, particularly the net radiative flux and the storage of heat in the soil.

Radiation. The old Callendar receiver and recorder of solar radiation were replaced in May 1955 by a Kipp solarimeter linked with a recording potentiometer. A simple portable solarimeter is being built for field use among growing crops.

A Gier and Dunkle type radiometer has been built and used. When this is exposed above a crop its electrical output is proportional to the *net* radiation received by the crop and its underlying surface. So, by day, it gives a direct measure of energy available for evaporation and heating; and, by night, the amount derived from condensation and by cooling. Tests during cloudless days in August showed a good correlation between net income for a potato crop and total income on the Kipp instrument, the slope of the regression line indicating that the potato crop was reflecting 17 per cent of incoming solar radiation.

Heat flux in soil. Heat-flux plates have been made, calibrated and used in the field. The plate, of glass or paxolin, is thin and carries a thermo-couple array to measure the small temperature difference that may be set up between its two faces. Laboratory work has shown that plate response becomes less dependent on soil conductivity as the ratio of area to thickness is increased. For paxolin, 8 cm. square and 0·15 cm. thick, the sensitivity changes by only a few per cent for a six-fold change in soil conductivity. During the dry period from 18 August to 8 September plates in the potato crop showed that heat stored in the soil was often about one-tenth of

the net radiation income in a day. Later rain cooled the top soil, and the subsoil then supplied 10–30 cal./cm.²/day to the surface.

Other equipment. A large recording balance to hold ten normally spaced potato plants is being constructed for the department at the National Institute of Agricultural Engineering. This will provide a direct measure of evaporation and condensation per unit area of ground surface, and so will give a measure of the latent heat term in the energy balance.

Thermocouples have been made from copper–nickel tubes 0·5 mm. diameter, and used to measure leaf temperatures (see also (*a*) above). Inserted in the stems of arbitrarily chosen leaves, the leaf–air temperature differences has ranged from 7·3° C. (net radiation gain 0·68 cal./cm.²/min.) in sunshine to —1·7° C. (net radiation loss 0·12 cal./cm.²/min.) in darkness. There have been indications that as the net radiation income becomes small in late afternoon the leaf temperature may fall below air temperature because of cooling by maintained evaporation.

(c) *Miscellany* (J. L. Monteith, P. B. Flegg, I. Warman, M. Frère)

Short-period laboratory experiments have included: (i) Tests on titanium oxide elements for measurement of relative humidity, kindly given to us by British Scientific Instruments Research Association. (ii) An attempt to exploit an idea of Dr. D. C. Spanner (Imperial College, London) that the Peltier effect can be used to measure relative humidities close to 100 per cent. Encouraging progress has been made. (iii) Tests on varied designs of anti-radiation shields for thermocouples, and for small resistance thermometers. A reassuring result was that the device used in our field equipment is as satisfactory as much more elaborate shields.

Evaporation

Application of the results of previous work continues. Consideration of the data from American experiments at Wagon Wheel Gap and at Coweeta has indicated that Coweeta conclusions about the hydrological consequences of forest clearance may need re-examination. In a different kind of hydrological problem, an attempt has been made to estimate the annual evaporation loss from the 2,000 square miles of the Lake Volta that will be created if the damming of the River Volta does take place as part of the Gold Coast scheme for generation of hydro-electric power. This was an interesting exercise, for meteorological stations in the area are few and their records of short duration.

For the introductory lecture at the Wageningen Conference on "Physics in Agriculture" the opportunity was taken to outline the physical principles, and some of the soil and biological aspects of water use by plants. From the extended discussion of the topic it became clear that while there is still much that the physicist can do by himself, most progress will be made by co-operative activity of physicist, biologist and pedologist. In his individual contribution to the symposium J. L. Monteith showed that the small night-time rates of evaporation from grassland were controlled by a transport constant not very much greater than the molecular coefficient of diffusion of water vapour in air.

Irrigation at Woburn

After 1954, the kind of year in which we expect—and get—nothing out of irrigation of any crop, 1955 has been a welcome change, particularly from the end of June onward. For the first time since the Woburn experiment started there has been dry weather in July and August, and we have been able to see the effect of late summer irrigation. Crops were as in 1954.

Grass. A good uniform stand of S 37 Cocksfoot was available. Colour change in low-water plots appeared about mid-July.

Sugar beet. A very uneven stand, gappy after singling. Treated for mangold fly. Plants never recovered from bad and irregular start.

Barley. A very even crop that made all its growth while natural rain was almost adequate. Some rust on all plots.

Potatoes. Main crop, which grew well under all treatments. Mid-July colour contrast was most striking, the watered plots being much lighter green, with flowering appreciably delayed.

Up to the end of June there was little need for irrigation: thence, to mid-September demand was continuous, and was so successfully met by T. W. Barnes that C plots of grass, sugar beet and potatoes were kept within 1 inch deficit below field capacity.

As usual, the table that follows ignores intermediate levels of watering, and merely reports extremes of no irrigation (O plots) and full irrigation (C plots) at two levels of nitrogen dressing (N_1 and N_2) imposed on a standard basal dressing of P and K appropriate to each particular crop. There was rain in excess in the five weeks 9 May–13 June (5·9 inches).

Woburn Irrigation 1955

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield
Grass	25 Apr.–26 Sept.	9·3	—	ON_1 37·2	Dry matter cwt./acre 7 cuts
				ON_2 54·5	
			7·7	CN_1 63·5	
				CN_2 81·9	
Sugar Beet	25 Apr.–26 Sept.	9·3	—	ON_1 32·8	Sugar, cwt./acre
				ON_2 35·6	
			6·4	CN_1 43·9	
				CN_2 51·6	
Barley	25 Apr.–1 Aug.	7·1	—	ON_1 31·6	Grain, cwt./acre
				ON_2 40·4	
			1·4	CN_1 32·4	
				CN_2 39·4	
Potatoes	25 Apr.–26 Sept.	9·3	—	ON_1 10·8	tons/acre
				ON_2 11·4	
			6·3	CN_1 19·0	
				CN_2 21·7	

As in most previous years, extra nitrogen is more important than extra water for barley. The grass responded to both, and it may be that an even bigger response to irrigation might be obtained by increasing the nitrogen dressing beyond the N_2 level. The sugar-beet response is disappointing when compared with what is known to have happened on irrigated commercial crops. Irrigated potato yields are the best ever obtained at Woburn: the non-irrigated yields are much in excess of any others at Woburn in 1955. One wonders why.

Miscellany

A brief survey of the effect of the weather of 1954 on farming productivity indicated that yields of main crops were about average, and the chief effects of the poor summer were in the delays caused by bad weather, a higher incidence of disease, and poorer quality in crops harvested.

During the year the Institute of Physics has published a short monograph on *Humidity*, by H. L. Penman. This is intended for students in technical colleges, and though mainly standard material, it includes a little of our special Rothamsted experience in handling problems of soil and atmospheric humidity.

CHEMISTRY DEPARTMENT

R. K. Schofield

Fertilizer Placement

(G. W. Cooke and F. V. Widdowson)

Peas and Beans

In experiments on broad beans and peas both crops were picked green for market. Dressings of superphosphate and muriate of potash and a mixture of the two fertilizers were broadcast and worked into the seedbed and compared with dressings placed in a single band beside the seed. For both crops broadcasting of P, K and PK fertilizers gave only small increases in yield. Placed superphosphate gave several times the increases from broadcast dressings, while placed K and PK fertilizers were about twice as effective as broadcast dressings. The experiments also tested a mixture of complete NPK fertilizer. There was no consistent gain from nitrogen dressings used for either crop. Adding nitrogen to the PK fertilizer depressed yields when the dressings were broadcast and had practically no effect when they were placed beside the seed.

Potatoes

One experiment on potatoes compared ammonium sulphate and muriate of potash broadcast over the seedbed with dressings placed at the side of the seed. With potassium fertilizer, placing the dressings beside the seed gave consistently higher yields than broadcasting. Placing and broadcasting of nitrogen gave closely similar increases in yield.

Combine-drilling potassium fertilizers for cereals

Four field experiments on barley compared combine-drilled dressings of potassium fertilizers with dressings broadcast and harrowed into the seedbed. There were good responses to potassium in all the experiments. At each centre a single dose combine-drilled gave higher yields than twice as much potassium broadcast. The experiments confirm earlier work carried out by the National Agricultural Advisory Service on chalky downland soils and suggest that all potassium dressings needed for spring-sown cereals should be drilled with the seed.

Comparisons of Methods of Application and Forms of Nitrogen Fertilizers

(G. W. Cooke and F. V. Widdowson)

Winter wheat

Three experiments on three varieties of stiff-strawed winter wheat compared three rates of " Nitro-Chalk " applied as a spring top-dressing. There were good responses to nitrogen at each centre. In one experiment 3 cwt./acre of " Nitro-Chalk " was sufficient for maximum yields, at the other two centres yields continued to rise as " Nitro-Chalk " top-dressings were increased to 9 cwt./acre. There

were no consistent gains from splitting the nitrogen dressing and drilling 1 cwt./acre of " Nitro-Chalk " with the seed in autumn, the remainder being applied in spring.

Spring cereals

Combine-drilling and broadcasting of ammonium sulphate was compared in experiments on spring cereals, and the additional effects of " Nitro-Chalk " top-dressings applied in May were measured. In the absence of top-dressings the overall increases given by combine-drilled and broadcast nitrogen were similar. When top-dressings were also given, broadcasting of the seedbed dressing gave consistently higher yields than combine-drilling. Conclusions on the value of different methods of application in individual experiments were conflicting. In one barley experiment heavy seedbed dressings gave large increases in yield, and additional top-dressings had little effect; in a second barley experiment both seedbed dressings and late top-dressings gave yield increases of roughly the same order. In a wheat experiment nitrogen applied at sowing-time had little effect on yields, but additional top-dressings gave sizeable increases. The only consistent conclusions were that when 0·4 cwt. N/acre applied on the seedbed was followed by 0·45 cwt. N as a late top-dressing yields were increased by roughly 50 per cent at each centre. Increases in yields of straw from nitrogen applied in various ways were generally similar to corresponding increases in yields of grain, but in one barley experiment late top-dressings increased the yields of straw, but had little effect on grain yields. The increases in straw yields given by top-dressings of " Nitro-Chalk " applied in May were of the order of the corresponding increases given by dressings of ammonium sulphate applied at sowing. The experiments suggest that for spring cereals late top-dressings of nitrogen are not a certain method of increasing grain yields without proportionate increases in straw.

In other experiments on spring wheat and barley, combine-drilling and broadcasting of both ammonium sulphate and calcium nitrate were compared. On the averages of two barley experiments and of three wheat experiments, the two forms of nitrogen gave closely similar increases in yield. There were no clear and consistent differences between yields given by combine-drilling and by broadcasting ammonium sulphate. When calcium nitrate was used, drilling gave slightly higher yields than broadcasting in the barley experiments, but for wheat broadcasting was somewhat superior. In 1954 experiments combine-drilling of ammonium sulphate gave consistently higher yields than broadcasting; this conclusion is not supported by the 1955 series. The work emphasizes the difficulties in recommending the " best " rates, times and methods of applying nitrogen for cereals. The value of any particular method must depend on soil and weather. By splitting dressings of nitrogen for spring cereals and applying part at seeding and the remainder as a top-dressing in May, it may be possible to obtain maximum responses over a run of seasons.

Potatoes

Seven experiments on main-crop potatoes tested three levels of dressing of ammonium sulphate and calcium nitrate. Yields in-

creased steadily with increasing dressings up to the maximum rate used (1·5 cwt. N/acre). At each rate of dressing calcium nitrate gave lower average yields than equivalent ammonium sulphate, and the high dressing of calcium nitrate (1·5 cwt. N/acre) was inferior to the medium dressing.

These experiments also tested the effect of splitting the dressing of nitrogen, part being applied on the seedbed and part as a top-dressing of "Nitro-Chalk" immediately before earthing up the potatoes. At both levels of manuring, split applications gave lower average yields of potatoes than dressings applied wholly before planting; this was true whether the spring-time dressing was ammonium sulphate or calcium nitrate.

Seven experiments on potatoes in each of the last three years have tested late top-dressings of "Nitro-Chalk". The results are summarized below in Table 1.

TABLE 1

Effect of late top-dressing on the yields of main-crop potatoes

Nitrogen fertilizer applied* cwt. N/acre		Yields of potatoes, tons/acre			
to seedbed	as top-dressing	1953	1954	1955	Mean (3 years)
none		9·0	8·8	7·2	8·3
0·5	—	10·7	9·8	8·4	9·6
1·0	—	11·8	10·1	9·3	10·4
0·5	0·5	11·3	9·9	8·9	10·0
1·5	—	—	9·9	9·7	(9·8)†
1·0	0·5	—	9·5	9·4	(9·4)†

* Seedbed dressings were in the form of ammonium sulphate, "Nitro-Chalk" was used for top-dressings.

† Averages of two years only.

In each year, higher yields of potatoes have been obtained by applying all the nitrogen before planting, than by saving a portion and applying it before earthing up the potatoes. In addition, another series of experiments carried out in 1953 showed that, when sufficient nitrogen was given before planting, late top-dressings failed to increase yields at all.

Kale

In two experiments on kale, almost identical increases in yields were given by calcium nitrate and by ammonium sulphate at both centres. The experiments also tested the effect of splitting the dressings of nitrogen fertilizers, part being applied before sowing and part as a top-dressing of "Nitro-Chalk" at the beginning of July. Split applications gave slightly higher yields than dressings applied wholly at planting.

MEASUREMENT OF "SUPERPHOSPHATE EQUIVALENTS" OF OTHER PHOSPHATE FERTILIZERS

(G. E. G. Mattingly)

In a series of pot and field experiments started in 1952 and now concluded, the "superphosphate equivalents" of other phosphate fertilizers have been estimated from (*a*) the crop yields, (*b*) the

phosphorus contents of the crop and (*c*) percentage of phosphorus in the crop derived from the fertilizer. In order to obtain estimate (*c*) the same small amount of ^{32}P-labelled phosphate was introduced into every pot or plot.

In the pot experiments ^{32}P-labelled monocalcium phosphate was applied in solution and the soil thoroughly mixed. The superphosphate (given at two rates) and the other phosphate fertilizers (given at an intermediate rate) were then mixed in as powders immediately before sowing. Table 2 gives a summary of some results from an experiment with radish on acid soil (pH 5·3), comparing dicalcium phosphate and Gafsa rock phosphate with superphosphate as standard.

TABLE 2

Comparisons of "superphosphate equivalents" of dicalcium phosphate and rock phosphate in pot experiments on radish

(All pots received 2·00 mg. P as ^{32}P-labelled mono-calcium phosphate per pot)

Inactive fertilizer	P applied, mg. P/pot	(*a*) Yield, g./pot	(*b*) P in crop mg./pot	(*c*) percentage P from, fertilizer	"Superphosphate equivalent" (*a*)	(*b*)	(*c*)
None	0	2·34	2·91	9·24	—	—	—
Superphosphate ...	15	5·16	7·57	5·68	—	—	—
Superphosphate ...	30	7·36	14·35	3·89	—	—	—
Dicalcium phosphate	22·5	6·25	9·66	4·58	22·1	20·3	23·1
Gafsa rock phosphate	22·5	5·74	12·13	3·50	1·87	25·9	35·4

Results by the three methods agree for dicalcium phosphate, but not for rock phosphate. It is suggested that phosphate diffuses only slowly from rock phosphate dissolving in an acid soil, and that local concentrations of phosphate are produced. If phosphate is taken up preferentially from these phosphate-enriched spots, the specific activity of the phosphate entering the plant would be lower than in plants grown in pots through which the unlabelled fertilizers had spread more evenly. This result, which was obtained with several samples of rock phosphate in this experiment, confirms similar observations in a previous experiment with ryegrass.

A field experiment with F. V. Widdowson used the same three methods to estimate "superphosphate equivalents" of fertilizer residues from heavy dressings of superphosphate on the same acid soil. Superphosphate was applied broadcast on plots at three rates of application and rock phosphate at a single rate in 1954; the site was cropped with barley in 1954 and ploughed in the autumn. In 1955 superphosphate, at four rates, was broadcast and harrowed into plots that did not receive any phosphate in 1954. 0·1 cwt. P_2O_5 as ^{32}P-labelled superphosphate was drilled with the seed on all plots in 1955, which were cropped again with barley. Results are given in Table 3 for a sampling 6 weeks after sowing and at harvest.

"Superphosphate equivalents" of the residues by all three methods at the first sampling were about one-quarter of the amount of superphosphate applied one year previously. At harvest, however, while "superphosphate equivalents" from yield measurements had not increased, those from phosphorus uptake and from measurements of specific activity had increased considerably. It is considered that this may indicate uptake of phosphorus in the late stages of growth from fertilizer residues that were buried by ploughing.

The "superphosphate equivalent" of rock phosphate applied a year before was very small in this experiment, both at the first sampling and at harvest. Further measurements will be made in 1956 on the same site, using ryegrass as the test crop.

TABLE 3

Field experiments on barley 1955

All plots received 0·1 cwt. P_2O_5/acre as ^{32}P-labelled superphosphate drilled with the seed. Measurements: (i) 6 weeks after sowing; (ii) at harvest (grain only).

Inactive fertilizer (broadcast)	Year applied	P applied, cwt.P_2O_5/acre		(*a*) Yield, cwt./acre	(*b*) P in crop, cwt.P_2O_5/acre	(*c*) Specific activity *	Superphosphate equivalent, cwt.P_2O_5/acre (*a*)	(*b*)	(*c*)
None		0	i	1·95	0·0082	41·8	—	—	—
			ii	11·2	0·0923	9·44	—	—	—
Superphosphate	1955	0·375	i	3·72	0·0247	20·8	—	—	—
			ii	19·7	0.139	6·86	—	—	—
" "	"	0·75	i	4·78	0·0364	14·6	—	—	—
			ii	23·3	0·162	6·16	—	—	—
" "	"	1·50	i	5·22	0·0492	9·5	—	—	—
			ii	25·1	0·176	4·77	—	—	—
" "	"	3·0	i	6·42	0·0694	6·4	—	—	—
			ii	29·1	0·211	3·55	—	—	—
" "	1954	0·75	i	2·78	0·0156	29·8	0·16	0·16	0·12
			ii	16·4	0·133	7·06	0·19	0·34	0·38
" "	"	1·50	i	3·39	0·0227	23·9	0·30	0.34	0·25
			ii	19·9	0·152	5·94	0·41	0·60	0·75
" "	"	3·0	i	4·82	0·0373	12·9	0·87	0·82	0·92
			ii	23·0	0·180	4·81	0·74	1·30	1·41
Rock phosphate	"	3·0	i	2·34	0·0121	33·4	0·12	0·08	0·07
			ii	17·0	0·134	7·18	0·22	0·35	0·35

* As percentage of specific activity of the placed superphosphate.

DETERMINATION OF LABILE ORTHOPHOSPHATE BY ISOTOPIC EXCHANGE

(O. Talibudeen)

Isotopic exchange experiments reported previously were extended during the year to several soils from Rothamsted and forest nurseries. In these experiments the isotopic exchange of orthophosphate ions was measured in a suspension of 0·5 g. soil with 100 ml. 0·0001*M*-citrate + 0·02*M*-KCl adjusted to the acidity of the soil. The composition of this solution was designed to replace the exchangeable polyvalent cations in the soil by K^+ or NH_4^+ and keep the ionic strength of the solution at a reproducible constant level. Using this procedure isotopic exchange was practically completed in 150 hours at 25° C.

In an alternative procedure, the polyvalent cations were exchanged by leaching with a small volume of *M*-KCl, and the samples were then suspended in 0·001*M*-KCl. Although equilibrium was reached more slowly, the results indicate that citrate at only 0·001*M* does not actually dissolve any orthophosphate that was non-labile in the original sample.

If orthophosphate is added to the solution containing 0·001*M*-citrate and 0·02*M*-KCl, isotopic exchange is not complete in 150 hours at 25° C.

Measurements made to test the effect of pH on the pool of labile P emphasize the importance of controlling the pH of the sytem during isotopic exchange experiments. They suggest that the labile P is very sensitive to pH changes in the range 7·0–7·5 for calcareous

soils and 5·5–7·0 for acid soils. The simple expedient employed in these isotopic exchange experiments is that the original pH of the solution is adjusted to the acidity of the soil, so that it does not change by more than 0·1 unit after equilibration with the soil.

During the year, considerable attention was given to the possibility of deriving diagnostic information regarding the status of phosphate residues in soils from curves for the rate of isotopic exchange with radioactive phosphorus obtained during the last three years. These curves suggest that the rapid interchange of orthophosphate ions ends after approximately 24 hours, whereas a slower exchange ends around 150 hours. Values of labile P measured after 24 and 150 hours exchange are tabulated for groups of soils which afford interesting comparisons. (Table 4.)

TABLE 4

Labile orthophosphate in Rothamsted and Forest Nursery soils

Expressed as mg. P/100 g. soil

		24 hours	150 hours	P_{24}/P_{150}
1. Hoosfield Exhaustion Land.	(*a*) No phosphate	2·9	4·8	0·61
	(*b*) FYM before 1901	7·7	11·0	0·70
	(*c*) Superphosphate before 1901	6·7	9·2	0·73
2. Broadbalk	(*a*) No phosphate or $(NH_4)_2SO_4$	2·6	4·5	0·58
	(*b*) Superphosphate	59·5	80·4	0·74
3. Highfield	Slightly acid	13·6	16·0	0·85
4. Sawyer's	Very acid	5·0	9·0	0·56
5. Four-course Rotation	Superphosphate			
	(*a*) 1st year	7·7	8·4	0·92
	(*b*) 2nd year	5·9	7·8	0·76
	(*c*) 5th year	3·9	8·0	0·49
6. Wareham	No phosphate	0·88	1·3	0·68
	Superphosphate	3·8	4·0	0·95
7. Kennington	No phosphate	8·1	12·4	0·65
	Superphosphate	14·1	15·5	0·91
8. Ringwood	No phosphate	8·0	8·7	0·92
	Superphosphate	14·7	14·7	1·00

Generally the application of fertilizer superphosphate is reflected in the increase in labile phosphorus measured at 24 and 150 hours. However, the labile phosphorus at 24 hours, expressed as a fraction of the total labile phosphorus, appeared to be a good index of the status of residual phosphate. Soils with recent applications of fertilizer phosphate showed substantial increases in this fraction. The effect of the year of application is clearly shown in the Hoosfield Exhaustion Land soils and the Four-course Rotation soils fertilized with superphosphate.

Assay of "soft" β-particle emitters

Work reported last year was repeated and extended to ^{35}S and ^{14}C estimated as $BaSO_4$ and $BaCO_3$ respectively. Self-absorption curves

for ^{45}Ca, ^{35}S and ^{14}C were worked out, which used in conjunction with the gas proportional counter now make the absolute determination of these elements possible. During the year the proportional counter was set up and standardized against ^{32}P measurements.

Nutrition Problems in Forest Nurseries

(B. Benzian and R. G. Warren)

Needle tip-burn

In the Rothamsted Report for 1953 mention was made of a symptom called " needle tip-burn " which had been observed for a number of seasons in Sitka spruce seedlings and transplants at Sugar Hill Nursery, Dorset. This nursery is on a very acid sandy soil which had previously carried *Calluna* and scrub pine. The symptoms tend to appear after a hot spell in midsummer. They occur on many of the fertilizer plots, but have only rarely been observed on plots which have received a dressing of a standardized compost made from bracken and hop waste.

During the 1955 season foliar applications of several micro-nutrients, i.e., copper, zinc, manganese and molybdenum, were tested on Sitka spruce seedlings at Sugar Hill Nursery. On plots which had received a foliar spray of copper sulphate applied in June at the rate per square yard of 0·16 g. Cu. in 300 ml. water, tip-burn symptoms were completely absent until the middle of August and developed only slightly during the remainder of the season. Plots without copper sulphate showed tip-burn from the beginning of August, the symptoms increasing in severity throughout the summer and autumn. At the end of the season the mean height of the " no copper " plots was 1·9 and of the " copper " plots 2·8 inches. None of the other micro-nutrients appear to have reduced the symptoms.

In experiments on both Sitka seedlings and transplants raised in 1955 testing fertilizer and compost made from bracken and hop waste, tip-burn developed on fertilizer-treated plots but was absent from compost plots. Beds which had received both compost and fertilizer together showed slight symptoms. The hop waste used in the making of compost is known to contain several hundred parts per million of copper, and a compost dressing of 10 lb./square yard generally prevents the appearance of the symptoms.

Methods of formalin applications

Although formalin applied as a drench (formalin diluted with water approx. 1 in 20) has proved consistently good in experiments extending over many seasons and soils, it has not been found easy to use the method on a large scale in Conservancy Nurseries because of the difficulty of applying large volumes of liquid by machine and the lack of a sufficient water supply in some of the nurseries. In 1955 neat formalin was placed in drills approximately 2 inches deep and 1½ inches wide with 9 inches between the drills. The treatment was applied either in December or in February at rates of 25 and 50 ml./yard of drill. The seedlings above the formalin drills compared favourably with those on plots raised with formalin drench. As there was little sideways-spread of the effect of neat formalin, the test will be repeated in 1956 with closer spacing of the drills.

Root examination

Mr. D. M. Griffin, working under Dr. Garrett, Director of the Sub-Department of Mycology, Botany School, Cambridge, has continued mycological examinations of plants from many of the experiments. The summary of the main result of his investigation is the conclusion that stunting in coniferous seedlings is not due to root-rot. J. B. Goodey, Nematology Department, has continued his study of nematodes in experiments at Ringwood Nursery.

Fertilizer Experiments on Oil Palms

(W. B. Haines)

The results from fertilizer experiments on oil palm in Africa, designed and directed by the late Dr. E. M. Crowther and referred to in the Report for 1949 have been reassessed. Some of the experimental fields have reached the end of their economic life, and all have revealed most of the information to be expected from them. The volume of the records available must be exceptional in the annals of field experimentation, for in 10 various sites a total of nearly 16,000 palms were individually recorded for 14 years; this has entailed nearly a million weighings of fruit bunches. Response to potassium was the most important and consistant result, showing highly economic possibilities. Phosphorus had good effects on a soil of very sandy type, but there were anomalies on a gravelly clay apparently connected with the variety of palm. Nitrogen did not prove to be markedly deficient, nor did limestone or magnesium produce positive results. The responses to applications of phosphate or potash were reflected more in the total phosphorus and potassium contents of these soils than in the amounts extracted by dilute acetic acid.

A feature of theoretical interest and of great importance to experimentalists working with this crop emerged from these records because of their long unbroken continuance. Earlier records from oil-palm experiments appeared to be statistically intractable. It is now found that much of the difficulty had arisen from cyclic fluctuations of yield with periods of three, four or five years. A three- to four-year period is most marked in the individual palm. Apparently the environment tends to keep them in phase, for the cycles do not disappear by smoothing when examining results from plots of 48 palms. Unless results are taken for the period of a complete cycle the estimate of error may be unduly large, and natural rhythmic fluctuations may be mistaken for experimental effects. Most unusual sub-normal items of variance also make their appearance. The climate of Nigeria, where most of the experiments were situated, has a very marked annual rain cycle, and it is considered that the three-year yield rhythm may be a compounding of this with a shorter cycle in the palm itself of nine months effective period. Yields from large bodies of palms tend to fall into a five-year cycle, which has a possible explanation in an alternation of activity between the formation of flower-bud and fruit, very roughly analogous to that which produces an alternation of crops in some varieties of apple. In this case the half-period is $2\frac{1}{2}$ years between bud formation and ripening of fruit. The five-year cycle has sometimes been so marked that the years of minimum yield have caused alarm.

The records of these experiments have also supplied valuable measurements of the increase of poaching of fertilizers by root action extending across plot boundaries, and of the rate of fading of well-established effects after the treatment has been stopped.

Soil Nitrogen

(J. M. Bremner and K. Shaw)

It is well established that a considerable amount of the nitrogen applied as fertilizer cannot be accounted for by analysis of the crop and soil. For example, about two-thirds of the nitrogen applied annually to the Broadbalk wheat plots is not recovered by such analysis. So far it has not been possible to estimate how much of this loss is due to drainage and how much to gaseous loss of nitrogen, but recent work in America has suggested that gaseous loss of soil nitrogen is much greater than previously suspected, and that under some conditions this loss may be very serious. J. M. Bremner and K. Shaw have therefore started an investigation of the factors affecting denitrification in soil in which particular attention has been given to soil samples from the Broadbalk plots. Preliminary work in which samples from these plots were treated with nitrate and incubated at 25° C. for 80 days showed that no serious loss of nitrate occurred whatever the moisture content. It was found, however, that extensive loss of nitrogen occurred when small amounts of glucose, cellulose or straw were added to water-saturated soils. For example, total nitrogen analyses showed that more than 70 per cent of nitrogen added as nitrate to Broadbalk plot 7 was lost in 2 days when the soil was treated with glucose, saturated with water and incubated at 25° C. A study of the effect of adding different amounts of glucose to water-saturated Broadbalk soil showed that maximal loss of nitrogen occurred when the amount of carbon added as glucose was about three times the amount of nitrogen added as nitrate. When smaller or greater amounts of glucose were added the loss of nitrogen decreased. Investigations of the factors affecting loss of nitrogen on addition of glucose and nitrate to water-saturated Broadbalk soil gave the following results :

1. The percentage loss of added nitrogen was about the same whatever the rate of application of nitrate.
2. Denitrification was very rapid at 25° C.; the loss of nitrogen after 3 days was practically the same as after 20 days (80–85 per cent).
3. The rate of denitrification increased with temperature; practically no denitrification occurred at 2° C.

Most of the nitrate-nitrogen not lost as gas on addition of nitrate and glucose to water-saturated Broadbalk soil could be accounted for as ammonia-nitrogen in the soil.

No loss of nitrogen occurred when ammonium salts or organic nitrogen compounds such as glycine, alanine or urea were added instead of nitrate. A study now in progress of the effect of the soil pH on denitrification indicates that the rate of denitrification of nitrate increases with pH and that no denitrification occurs below pH 4·5.

Denitrification of nitrate upon addition of straw to water-saturated soils is markedly slower than when glucose is added, but the loss in 20 days can exceed 80 per cent if sufficient straw is added. No extensive loss of nitrogen was detected when soils treated with nitrate and glucose were incubated at moisture contents below their water-holding capacities. Denitrification of nitrate appears to be entirely due to the activities of soil micro-organisms, as it is completely inhibited by toluene.

In continuation of earlier work on amino sugars in soil, J. M. Bremner investigated the nature of the 2-amino sugars present in soil hydrolysates. Glucosamine and galactosamine were identified, the former being isolated by ion exchange techniques.

Work by K. Shaw on the decomposition of " mat " on permanent pasture has been extended to include samples taken from two areas in North-West England where the problem of " mat " formation is an important factor in soil fertility. The sites were carefully chosen so that the samples obtained were taken from under pure stands of *Nardus* and *Deschampsia Flexuosa*. Analyses and fractionations of the two samples of " mat " showed that they were very similar in composition to the " mats " produced under the rather artificial conditions of the Park Grass Plots.

Organic Phosphorus in Soils

(P. W. Arnold)

Work on the characterization of the organic phosphorus-containing material which can be extracted from soils has been continued. Attention has been given to that part of the organic phosphorus which, although isolated along with the inositol phosphate, does not behave as inositol phosphate on paper electrophoretograms. This fraction of unknown constitution possesses considerable electrophoretic mobility but does not migrate as a compact spot. Attempts to release recognizable organic phosphorus-containing substances from this fraction by hydrolysis, etc., have not, as yet, been successful.

A quantitative study of the products of the progressive hydrolysis of phytic acid at pH 3 (120° C.) has been made, using a paper electrophoretic technique. Experimental results have been compared with calculated figures based on a dephosphorylation involving six consecutive first-order reactions with a single velocity constant. It was concluded that, although values for the velocity constants in the successive stages of the dephosphorylation were all of similar magnitude, the tetra-, tri- and di-phosphates of inositol were slightly less stable than the hexa- and/or penta-phosphate of inositol. Peak concentrations of tetra-, tri-, di- and mono-phosphates occurred at the stages when 29, 43, 63 and >80 per cent of the total phosphorus respectively had been released as inorganic phosphate.

Soil Manganese

(S. G. Heintze)

Results of applying various manganese materials to an alkaline manganese-deficient " skirt " fen in pots and growing oats showed that highly significant increases in grain yields could be obtained from application of manganese versenate, manganese hydroxy-

quinolate, manganese pyrophosphate and manganese sulphate, despite the plants exhibiting signs of greyspeck. Manganese versenate was somewhat superior to other materials for increasing grain and stem yields, while manganese sulphate was outstanding for its effect on leaf yield. Rhodonite increased grain yield below the level of significance and had no effect on leaf and stem yields or on manganese content of grain. The increase in total manganese content of grain was smallest where manganese versenate had been applied.

Estimation of various soil manganese fractions at the end of the experiment showed that manganese added as versenate or hydroxyquinolate had been converted into forms partly extractable by ammonium acetate with hydroquinone. Recovery of manganese added as pyrophosphate was found only in alkaline pyrophosphate and neutral versenate extracts.

The effect of liming on various soil manganese fractions of a manganiferous clay loam was studied by analysing soil samples before and at intervals after liming of plots from Agdell Field, which had become acid in parts. All acid plots contained more manganese in the various fractions than corresponding alkaline plots. The decrease in exchangeable and alkaline pyrophosphate-soluble manganese as a result of liming was markedly less at comparable pH values on the half of the field which contained more accumulated organic matter, the clover side, than on the fallow side. More readily reducible manganese higher oxides were found after liming on the fallow side. The readily reducible fraction constituted a much larger proportion of total manganese than the neutral pyrophosphate soluble fraction on acid and alkaline plots. This fraction showed only small differences with time after a first initial decrease after liming.

The study of the nature of organic manganese complexes was continued. The behaviour of manganese of various extracts subsequent to sodium chloride extraction of organic soils was followed by paper electrophoresis and by dialyses of such extracts against salt solutions. It was found that the direction of migrating manganese depended, amongst other factors, on the nature of the extract and the reaction. The retention of non-dialysable manganese, whether present in or added to extracts or humic acid preparations, was not related to readily oxidizable carbon content of the organic matter, and was in some cases not affected by pre-removal of dialysable organic matter.

General

A. C. D. Newman joined the staff in October, and A. Penny was appointed to assist with the experimental field work. J. E. A. Ogborn resigned to take up a post with the Abyan Board in the Aden Protectorate, and was replaced by the appointment of B. Harrington.

P. W. W. Daborn of the Forestry Commission was further seconded for the field work on nutrition problems in forest nurseries. J. C. Wilcox, who had been seconded to the Department for training in field work, returned to the National Agricultural Advisory Service. J. A. R. Bates, P. B. Tinker and J. B. M. Vogt of the Colonial Agricultural Research Service worked in the Department for varying lengths of time while being trained in field experimentation. R. K.

Cunningham and A. Pinkerton, also of the Colonial Agricultural Research Service, were seconded for a year's training in soil fertility. R. A. Christ of Basle University worked in the department for 9 months. G. W. Cooke carried out a study for the European Productivity Agency of the Organization for European Economic Co-operation on "The agronomic value of non-sulphuric acid phosphate fertilizers". He visited research institutes in Denmark, Sweden and Norway to collect information for this study. He also attended the Meeting of the Association Internationale d'Études Phosphatières held in Blois, France and contributed a paper. A. W. Taylor, who had leave from the Physics Department during the tenure of a post-doctorate fellowship at the University of Wisconsin, was transferred to the Chemistry Department on his return.

PEDOLOGY DEPARTMENT

A. Muir

A. Muir represented the Agricultural Research Council on the British Agricultural Delegation to the U.S.S.R. Dr. D. H. Ya'alon completed his clay mineralogical studies on soils formed over clay-with-flints and has returned to Israel. Mr. C. Ollier, a Colonial Office student in training with the Soil Survey, has collaborated in this particular study. Mr. D. H. Khan of Dacca University is spending two years studying soil genesis. Dr. J. H. Rayner has been appointed to the staff to work on the synthesis of clay minerals.

Soil Mineralogy

During the year mineralogical investigations of soils from different regions of Africa have been completed, and reports on soils from the following countries have been prepared for publication : (1) Nyasaland, (2) Kenya, (3) Tanganyika.

(1) *Nyasaland*

Mineralogical examination of the sand and clay fractions of a series of soils and parent materials from the Lower Shire Valley has confirmed the field evidence and shows that the bulk of the material forming the valley slopes is of a localized nature. In conjunction with geomorphological data it seems possible to ascribe the origin of much of the superficial deposits to a kind of pedisedimentation brought about in part by the various earth-movements associated with the Rift Valley. (A. Muir and I. Stephen.)

(2) *Kenya*

This investigation arose out of the problem of uneven growth of crops on several estates in the Athi Plain region of Kenya. Over hundreds of square miles occur roughly circular " islands " of 20–50 yards diameter at 50–100-yard intervals, on which crop growth is very much superior to that in the surrounding area. The phenomenon seems best described as an example of what has generally come to be known by the Australian word *gilgai*, and the pattern seems to be that of the normal or round gilgai.

A study of the mineralogy of the underlying rocks (soda-rich intermediate lavas including trachytes and phonolites) and the sand fractions of the soils shows that all the profiles studied have a common origin, and appear to result from the combined influence of climate and relief on the alkali-rich rocks. Under such conditions the rock weathers directly to montmorillonite, the high swelling properties of which appear to be a dominant factor in the production of gilgai relief. (A. Muir and I. Stephen.)

(3) *Tanganyika*

A series of soils from two areas (Kongwa in the Central Province and Nachingwea in the Southern Province) have been investigated. The parent rock, while in general an amphibolite, is sufficiently

varied locally to cause differences in the appearance of some of the shallower soils. In the main, however, since the soils are formed on a mantle or pedisediment, there has been much mixing of the weathered products, and it is only by an examination of the resistant heavy minerals that an indication of the probable source rocks is obtained.

The clays of the red soils are characterized by a predominance of kaolinite, whereas the more poorly drained grey soils have a disordered kaolin. Other components of the clays are iron oxides and minor amounts of illite. The pallid soils contain moderate amounts of montmorillonite in the weathering zone, some of which persists into the soil. The mbuga and black soils contain montmorillonite or illite with subordinate kaolin. (A. Muir and I. Stephen.)

Rock Weathering

A study of rock weathering and soil formation on igneous soils in Shropshire has been commenced. The parent rocks are of varied composition and include rhyolite, augite-andesite, dolerite and picrite. (I. Stephen.)

Micropedology

During the year research on improving methods of preparing thin sections of soils for optical study has been carried out. The sectioning of soils in this department was started using kollolith as the impregnating medium, but temporary failure of the supply led to the search for other suitable media. Satisfactory results have been obtained using " Ceemar Embedding Resin ", enabling sections of 20–30μ in thickness to be prepared, but preparation of sections of soils of very high clay content has proved difficult, and further experimentation is proceeding on this problem.

Although much of the work so far has been concerned with perfecting techniques, a series of sections of red soils (terra rossa, rotlehm, etc.) from Cyprus have been prepared for future study, and a start has been made in sectioning local soils developed on chalk, clay-with-flints, etc. In the soils developed on clay-with-flints and allied deposits, preliminary studies of the sections show a marked micromorphological change in the profiles, the dense " braunlehm-like " character of the lower horizons being replaced in the surface layers by a fabric characterised by the flocculated structure elements of a braunerde, this fabric alteration apparently being related to weathering under present-day conditions. (I. Stephen and D. A. Osmond.)

Clay Mineralogy

Soil Morphology and Mineralogy

No work has been done on this during the year. A microfocus X-ray tube is being constructed with which it is hoped X-ray examination (radiographic and diffraction) of soil sections may be made in the manner of petrofabric analysis. (G. Brown and G. C. Dibley.)

Dickite

The mineralogical work on dickite is now completed and has been prepared for publication. (G. Brown.)

Pyrite

X-ray identifications of pyrite and pyrite pseudomorphs have been made for Dr. F. Smithson. The pseudomorphs were shown to be mixtures of goethite and haematite, the proportions of these influencing the colour. The very dark brown pseudomorphs contained more haematite than the light brown. A single pseudomorph was examined by single crystal methods and the goethite and haematite was shown to be polycrystalline, with no preferred orientation with respect to the pyrite. This work has been written up and will be published in Dr. Smithson's paper. (G. Brown.)

As a corollary to this work a number of pyrite pseudomorphs of different habit and from different environments are being investigated by single-crystal methods to find the effect of habit and environment on the oxidation. (G. Brown and G. C. Dibley.)

Collophane

Examination of the insoluble sand fraction of the Upper and Middle Chalk has revealed the presence of collophane apparently derived from fish. The properties of this occurrence have been investigated by optical and X-ray methods, and this work has been accepted for publication by the *Mineralogical Magazine*. (G. Brown and C. D. Ollier.)

Clay-with-flints

The phase of the work mentioned in last year's annual report has been completed. Mineralogical examinations of clay, silt and sand fractions and detailed mechanical analyses have been carried out for five complete profiles. The results show that four of the profiles are polygenetic. Changes in particle-size distribution curves are accompanied by mineralogical changes. The chief pedological change in the clay minerals appears to be an increase in the proportion of dioctahedral vermiculite at the expense of dioctahedral mica in the surface horizons. (G. Brown and D. H. Ya'alon.)

Quantitative analysis

A method for the estimation of free iron oxides in clays by X-ray methods is being investigated. The basis of the method is the formation of haematite from iron oxides on heating to moderate temperatures in air. The proportion of haematite can then be estimated by an internal standard method. With mechanical mixtures of iron oxides and clays heating gives sharp haematite reflections, and for concentrations in the range 5–10 per cent, haematite can be estimated with an accuracy of ± 10 per cent in the presence of mica, kaolinite or montmorillonite minerals by comparing peak intensities. However, when the iron oxide is precipitated on the clay, heating gives broad haematite reflections, and estimations based on peak intensities give low results. An attempt to overcome this difficulty by using integrated intensities is being made. (G. Brown and R. Farrow.)

Chalk residue

The insoluble clay fraction of the Upper and Middle Chalk samples investigated in connection with collophane have been examined.

The bulk of the clay consists of a mixture of a mica and a montmorillonite mineral. The mica seems to be concentrated in the coarser clay. (G. Grown and R. Farrow.)

Techniques

A simple vapour-pressure method of adding glycerol to clay specimens has been tested and adopted for routine identifications. An extrusion device for banded powder specimens using hypodermic needles has been developed. A 9·0-cm. powder camera has been modified so that it can record spacings up to 100 Å. (G. Brown, G. C. Dibley and R. Farrow.)

Anglesey

The X-ray patterns of a number of soil clays taken in previous years have been interpreted. The results will be included in the memoir to the Anglesey sheet of the Soil Survey. (G. Brown.)

Shropshire

X-ray diffraction has been used to identify the finely crystalline materials encountered in the rock-weathering study which is being carried out by I. Stephen. A mineral which gives excellent fibre patterns, fibre period about 5·3 Å., has been identified as a mineral of the montmorillonite group, and structural work on this and closely related minerals is being carried out. (G. Brown.)

Miscellaneous

In addition to materials already mentioned, soil clays from Aden, Cyprus, Kenya, Tanganyika, Nyasaland, Israel and St. Helena have been examined. In England soils and clays from Lincolnshire, Buckinghamshire, Hertfordshire and Kent have been examined. (G. Brown and R. Farrow.)

The sorption of water by clay minerals

The studies on the crystalline swelling of montmorillonite minerals have been continued. The influence of different monovalent cations and composition of the substrate on the amount of adsorbed water required to give different sheet separations has been investigated. The chief obstacle to accurate evaluation of the internally held water is the correction for that held externally, but this has now been satisfactorily overcome by the use of lithium-treated montmorillonites (see earlier Reports). The very slow approach to equilibrium of these systems has meant that comparatively few results could be obtained on one apparatus, but during the year a multiple sorption apparatus incorporating six quartz spiral balances and a manifold to which six detachable X-ray samples could be sealed has been constructed and has greatly improved matters. A paper describing the work carried out during the last four years is in preparation.

The calorimeter described in last year's Report has been used to measure the heat capacity of sodium montmorillonite–water systems as a function of the water content and the temperature. Up to 20 per cent water the heat capacity at room temperature varies roughly linearly, but is slightly greater than would be expected if the heat capacities of the dehydrated mineral and liquid water were

additive. Superimposed on this relation were significant fluctuations which appeared to be correlated with the crystalline swelling of the mineral. At lower temperatures the calorimeter behaved less satisfactorily, due to lead conductance, and it became necessary to modify the design. A new calorimeter of greatly increased precision has been designed for low-temperature work and for the further investigation of the small fluctuations already mentioned. A large part of the construction has been completed. (R. Greene-Kelly.)

Microcalorimeter

As foreshadowed in last year's Report, a microcalorimeter has been designed and constructed for the measurement of small heat effects occurring in clay systems. Since many heat changes occur over comparatively long periods, it has been necessary to aim at very constant conditions in and around the calorimeter. Since large clay mineral samples involve lengthy preparation and are difficult to disperse in heats-of-immersion studies, it has been necessary to develop sensitive methods of temperature measurement. The use of a thermistor as a temperature-sensitive element was investigated in detail and found to be satisfactory if its power sensitivity was arranged to be low. A Wheatstone-bridge circuit was used to measure the resistance of the thermistor, particular attention being paid to the elimination of parasitic potentials. The out-of-balance current was measured, using a linear galvanometer, this giving a sensitivity of about $3{\cdot}0 \times 10^{-5}$ C./mm. Alternatively a d.c. amplifier and recorder could be used. The thermistor was directly calibrated in joules with an electrical heater in the calorimeter at the time of the experiment. The calorimeter itself was a 300-ml. vacuum flask which was closed by a Perspex lid through which the stirrer, sample breaker and leads passed, and the whole was enclosed in a brass box which was itself immersed in a double thermostat. The evacuated samples, for heats-of-immersion studies, were enclosed in 2-cm.-diameter sealed glass bulbs and were broken under the selected liquid by screwing down a rod from outside the calorimeter. The results have shown that the precision of measurement of heat of immersion depended on the reproducibility of the blank heat of bulb breakage, which at present may vary by as much as 0·1 joule. Recently suitable bulbs have been obtained (from a glass-works), and in view of their reproducible size and wall thickness they are expected to be more satisfactory. The calorimeter has been tested by measurement of heats of solution of potassium chloride, and has been used to measure the heats of wetting of kaolinite and montmorillonite in water and salt solutions. Kaolinite evacuated at room temperature showed a heat of wetting in water which is roughly proportional to its surface area, 0·3 joule being evolved for every square metre wetted. Sodium montmorillonite showed a larger heat of wetting in water which was accompanied by slow heat evolution for several hours. If the expansion was limited to crystalline swelling, the thermal drift was found to disappear, and it therefore seemed that it was due to continued expansion and eventual breakdown of the clay crystals. A detailed investigation of the heat effects accompanying swelling phenomena in clays is in progress, in conjunction with X-ray and negative-ion adsorption measurements. It is also hoped to utilize the calorimeter in the

study of heats of solution of minerals. (R. C. Gallavan and R. Greene-Kelly.)

Organic complexes of montmorillonite

The structures of montmorillonite complexes and saturated organic compounds have been investigated. The orientations of ring compounds in saturated and aromatic complexes have been found to be similar (see last year's Report). The influence of di-substitution on any one ring atom in piperidyl rings has shown that there must be appreciable distortion of the tetrahedral bond angles in a similar way to that reported by Hassel for the chloro*cyclo*hexanes. Chain complexes have been found to show a puzzling variation in spacing with chain length, the most likely explanation being that it is due to C–C single-bond oscillations. The consequence of assuming this effect has led to the generalization that C–H—O (silicate) distances are always reduced from normal Van der Waal's distances in montmorillonite complexes.

The crystalline swelling of montmorillonite saturated with organic cations is shown to occur in certain organic liquids. The resultant interlamellar separation is determined entirely by either one or other of the molecules and not by combinations of them. This swelling clearly would interfere with the use of organic cation montmorillonites as molecular sieves, as has been suggested by Barrer and co-workers.

The competition for exchange sites on montmorillonite between ethylamine and inorganic cations has also been investigated. Whilst ethylamine ions are strongly sorbed in the absence of external concentrations of inorganic cations, the presence of a comparable inorganic cation concentration can reduce the sorption considerably. If ethylamine montmorillonite is washed with dilute sodium choride or even calcium bicarbonate solutions the nitrogen is rapidly and quantitatively removed. It seems therefore that such low-molecular-weight amines derived from plant and animal remains could not be retained for long in clay soils. This is in agreement with the "normal" swelling behaviour of montmorillonites found in soils. (R. Greene-Kelly.)

A thermal balance for clay mineral work

The d.t.a. method does not give quantitative data on water loss in clay minerals, as it measures temperature differences. It is sensitive to packing, conductivity and thermal reactions involving the generation or absorption of heat. The role of a thermal balance is to provide information on weight loss in minerals under the conditions existing in the d.t.a. apparatus, and it must have a comparable sensitivity. In addition, the sample size should be as small as possible, and in practice 100-mg. samples are used.

The balance consists of a silica coil spring suspended in a glass tube, which is separated from the furnace by two water-cooled collars with sliding vanes to shield the spring from radiation from the furnace. The sample is placed in a platinum bucket 1 cm. in diameter and 4 mm. in depth, which is attached to the spring by a thin platinum wire. The furnace is controlled by a chromel–alumel thermocouple suspended in the furnace space by the bucket, and attached to a Kent recorder which operates a powered variac.

Movement of the spring is followed manually with a cathetometer which can be read to 0·02 mm. and represents a change in weight of 0·05 mg. or 0·5 per cent of a 10 per cent weight loss on a 100-mg. sample. When working for the greatest accuracy, as in the 0–300° C. region on montmorillonite, the cathetometer is set at successive positions 0·010 cm. apart and the time of each reading recorded and correlated with the temperature. As the sample is so small, there are no packing effects, and the temperature in the sample is uniform.

The data of weight loss with time or temperature are converted to rate of weight loss with temperature to compare with d.t.a. curves. This operation has been programmed by J. Gower in the Statistics Department and is performed on the electronic calculator. Using different cams on the Kent recorder, the rate of heating can be varied from 20° per minute to 5° per minute, and when manually controlled the rate can be maintained at 2° per minute, so that intermediate stages between d.t.a. curves at 10° per minute and equilibrium-weight-loss curves can be obtained. Accuracy of setting and reading the cathetometer increases when the rate of heating is decreased.

Curves have been made for several kaolinites and dickite, halloysite, vermiculite and various montmorillonite samples. Work on clays from Broadbalk shows that the method gives a reliable value for kaolin content and is unaffected by particle size and organic matter in the soil.

The limiting factors in the accuracy of the method include the furnace-control system, the accuracy of setting the cathetometer and oscillation in the spring due to radiation effects in the furnace. Further work will be concerned with these points and in making the balance self-recording. (R. Greene-Kelly and A. H. Weir.)

Soil clays

The detailed investigation of the kaolinite–illite clays separated from the C horizon of the Broadbalk soils on clay-with-flint material has been continued. Confirmation of the estimation of kaolinite by differential thermal analysis has been obtained by the use of the new quartz-spiral thermal balance developed in conjunction with A. Weir. The difficulty of correcting the differential thermal curves for the presence of traces of organic matter is to a large extent avoided in the thermal balance, since the thermal effects detected by d.t.a. obtained from the oxidation of traces of carbon tend to magnify out of all proportion the amounts causing the effect. Simple X-ray comparison methods have been applied to the different size fractions, and whilst for the coarser fractions the amounts of kaolinite determined compared favourably with thermal methods, the finer fractions, which showed appreciable line broadening, gave useless results, at least when peak heights are compared. The possiblity that peak areas may provide a better method of comparison is being investigated, but clearly there is much to be said for thermal methods in such cases, for they are not so dependent on particle-size variation.

The study of the surface properties of the Broadbalk clays as a function of particle size has shown that the adsorption of water and polar organic compounds from the vapour phase at low pressures is more a function of the cation-exchange capacity than the extent of

the external surface. This suggests that crystalline swelling had occurred. It was estimated that the internal area was of the order of 300 sq. m./g., and allowing for the amount of non-expanding minerals, this showed that about one in three sheets expanded in this soil illite. This was not greatly effected by particle size. Thermal and ion-exchange studies are also in progress. (R. Greene-Kelly.)

Spectrography

Methods

The use of the Lundegårdh flame method for the determination of exchangeable bases in soils has now been discontinued. A considerable saving of time has been achieved by the use of a flame photometer for the determination of potassium and sodium and of the versenate method for calcium. Magnesium is determined spectrographically by the porous-cup method.

A spark spectrogaphic method for aluminium

In connection with Dr. Rayner's work on mineral synthesis, a solution spark method has been worked out for the medium spectrograph. The method is required to be rapid, to work with 0·1 g. of sample, and in the first instance only for determinations of Si, Al and Mg. The spectrographic technique is tedious when a single element is required, and only becomes competitive with colorimetric methods when several elements are to be determined.

The sample is taken into solution by fusion with sodium hydroxide or digestion with hydrofluoric and sulphuric acids. A nickel solution is used at 1,000 p.p.m. as internal standard and the line Ni 2981 Å. read against Al 3092 and 3082 Å. The plate is callibrated, using an iron arc and step sector, and single-step burns are used with four replications of each solution. Using Kodak B.10 plates, the greatest linearity of calibration is found when a density scale of $\frac{i_0}{i} - 0{\cdot}9$ is used. This gives a straight line between 1·1 and $\bar{1}{\cdot}7$. On the advice of Mr. Ballanger, National Agricultural Advisory Service, Bristol, all the cup electrodes are now heated to 500° C. before use to prevent boiling in the cups. This method is susceptible to changes in the sodium concentration of the solution. An accuracy of 3–4 per cent is obtainable. (A. H. Weir and J. Beckett.)

Geochemistry of lias shales

Investigations into the molybdenum content of the calcareous shales of the Lower Lias have shown that, where the whole extent of the formation has been examined, high concentrations are confined to the lower zones. The shales with high concentrations always contain between about 10 and 50 per cent calcium carbonate, and a correlation has been found between the content of molybdenum, nickel, copper and vanadium, on the one hand, and of organic carbon in excess of 2 per cent, on the other. When the organic carbon content is below about 2 per cent the shales contain fairly constant levels of these elements : Mo $<$ 5 p.p.m., Ni and Cu about 50 p.p.m. and V about 150 p.p.m. These levels increase with organic carbon in excess of 2 per cent in such a way as to suggest that their content

is proportional to the shale's present or past content of some organic constituent which does not normally occur in the basic 2 per cent. The amount of cobalt appears to be independent and is relatively constant at between 10 and 30 p.p.m. (H. H. Le Riche.)

During the year, analyses have been carried out for the Botany Department in connection with studies of the uptake of iron, vanadium and molybdenum in water-culture experiments. Trace-element analyses have also been done for the Grassland Research Station, Hurley, and for the Botany Department of the University of Southampton on crops where failure was suspected of being associated with trace-element deficiencies. (H. H. Le Riche.)

Trace elements in wheat shoots

Broadbalk was sampled in the last week of May 1954 for a small pilot experiment on the effect of fertilizer treatment on the trace-element content of wheat shoots. Plots Nos. 2, 3, 5, 8, 10, 13, 17 and 18 were selected as likely to show the greatest differences, and the top two-fifths of the field were sampled for shoots and soil (0–8 inches).

The analyses were done spectrographically, using the method of Farmer for copper, manganese and iron and the concentration method for the traces, cobalt, vanadium and molybdenum. Results on the total soils showed very small variation from plot to plot in the elements concerned. Iron was present at 5 per cent, copper 10 p.p.m. and manganese 0·1 per cent, cobalt 25 p.p.m., vanadium 60 p.p.m., molybdenum $<$ 10 p.p.m. The pH value of the soils is approximately 7·5 for all the plots except No. 8, where continued application of ammonium sulphate had resulted in pH values down to 5·5 in the lower part of section 1 of the plot. This in the bulk sample from the plot showed in the molybdenum uptake for the shoots, which was as low as 0·09 p.p.m.

Iron and manganese uptake in the shoots showed a ratio varying from 1·3 to 0·8, with the amount of iron varying from 100 p.p.m. in plots 3 and 18 to 60 p.p.m. in plots 2 and 17. Molybdenum shows a minimum of 0·09 p.p.m. in plot 8 and a maximum of 0·4 p.p.m. in plot 18. Cobalt, vanadium and copper show very little variation from plot to plot, the plants containing 6 p.p.m. copper, 0·05 p.p.m. cobalt and 0·15 p.p.m. vanadium.

There is a slight tendency for the amount (in p.p.m.) of the elements to increase in the plots with a low yield and a low weight per shoot, which leads to difficulty in the presentation of data. The variations shown in the elements between plots are not very large, and there is no deficiency in the soil. In plot 3, which has had no treatment since 1839, 30 γ of Mn and Fe, 2 γ of Cu, 0·08 γ of Mo, 0·05 γ V and 0·03 γ Co are removed per shoot from the soil reservoir, and no difference is found in the total trace-element contents of the soil from this plot compared with the others.

Plots 12 and 13 on Park Grass were sampled for Cocksfoot (*Dactylis glomerata*) in June 1955 just before the first cut when the plants were in flower. Whole plants were cut an inch above the ground and the samples divided and analysed in three parts, the flower, the woody stems and non-flowering stems. Plot 12 had no treatment and has a pH of 5·2 (1935). The unlimed part of plot 13 had

alternate dung and guano and a pH of 4·6, and the limed part a pH of 6·4. The plots were sampled in the fourth year after liming.

The opportunity was taken to try a composite scheme of analysis, 20 g. of dried material were wet-ashed, made up to 200 ml. and two small aliquots taken, one for sodium and potassium on the flame photometer and calcium by Lundegårdh technique, and the other for porous-cup determinations on phosphorus, manganese, magnesium, iron, copper and zinc; the remainder was concentrated for trace elements in the normal way.

Calcium in non-flowering shoots showed very little variation between plots, 0·34 per cent for plot 12, 0·31 per cent for unlimed plot 13, and 0·36 per cent for limed 13; for the stems and flowers the results were 0·15–0·2 per cent. Copper uptake followed the pH of the plots, and was the only investigated element to do so; unlimed 13 contained 6·5–70 p.p.m., 12, 4·5–6·0 p.p.m. and limed 13, 3·5–5·0 p.p.m. Molybdenum occurred at 0·05–0·09 p.p.m. in plot 12 and increased to 0·15–0·25 p.p.m. in unlimed 13, and 0·3–0·4 p.p.m. in limed 13. Vanadium is lowest in the latter, 0·04–0·08 p.p.m. and highest in plot 12, 0·06–2·0 p.p.m. Cobalt is very low in all three: unlimed 13, 0·07–0·18 p.p.m., plot 12, 0·04–0·08 p.p.m. and limed 13, 0·03–0·07 p.p.m. The figures quoted for molybdenum, vanadium and cobalt on plot 12 are very low for grasses, and so are the vanadium and cobalt figures on the limed half of plot 13. (A. H. Weir and J. Beckett.)

Soil Chemistry

A study of leaf leachates

Further work on the properties of leaf extracts has provided additional evidence for the presence of substances that inhibit the solution/reduction of hydrous ferric oxide. This has been demonstrated by comparing the extent of solution of ferric oxide caused by an untreated extract, a dialysed extract and a mixture of the untreated and the dialysed solutions. The dialysed extract is considerably less active than the untreated material, but nevertheless its activity is appreciable. Addition of the dialysed solution to the untreated extract causes a marked decrease in the mean extent of solution/reduction.

On the basis of earlier work, it has been difficult to reconcile laboratory results with field observations on the podzolizing properties of the two New Zealand species rimu and kauri (*Rep. Rothamst. exp. Sta. for 1953*, 61). Both these species shed their bark, and water extracts of the two barks possess approximately the same moderate activity. Comparison of the properties of leaf and bark extracts with a mixture of the two reveals a considerable difference between the two species; for the kauri, the mixed leaf and bark extract has virtually the same solution capacity per unit weight of plant material as the leaf extract alone, but with rimu, in the presence of the bark extract, the extent of solution of ferric oxide is decreased to less than half its original value. It is therefore apparent that compared with kauri bark, a rimu-bark extract has a much greater inhibiting effect on the reaction.

Using ion-exchange resins in conjunction with paper chromatography, it has been shown that for several tree species a large part

of the solution/reduction activity is due to the action of simple carboxylic acids and reducing agents present in the leaf extracts; the joint action of the two groups of compounds is appreciably greater than the sum of their individual effects.

Some success has been achieved in producing podzolization in columns of quartz coated with ferric oxide. In these experiments the sand columns were treated intermittently with dilute leaf extracts of a wide variety of species. In all cases considerable amounts of iron were lost from the columns. After standing for a few weeks the columns all showed clearly visible B horizons. So far as can be said at present, it seems that the formation of the B horizon is caused by drying out and consequent aeration of the upper layers of the column, but this question needs further study.

The study of the deflocculation of kaolinite suspensions by leaf extracts has been continued. It has been found that the initial dispersion caused by low concentrations of the extracts is caused by an irreversible sorption of organic compounds on the clay surfaces; the reflocculation produced at higher concentrations of leaf extract is reversible and may be counteracted by dilution. The effect of the irreversible sorption of the pH of flocculation is very marked; untreated kaolin, which is flocculated at pH values below 9, approximately, remains dispersed down to about pH 3 after treatment with a leaf extract. Both the deflocculation and flocculation stages are caused by large-molecular-weight compounds, since dialysis of the extracts has virtually no effect on the process.

While the action of kauri- and rimu-bark extracts on kaolinite seems to be due simply to the presence of polyphenols, the action of an aspen-leaf extract is much more complex. In the latter case several anionic species are present in the extract, and any one of these alone causes dispersion of the clay; one such substance that has been isolated is an acid which appears to be present in the extract as the salt of a weak base. It has been found that this compound, which is strongly sorbed on kaolinite, causes deflocculation of the clay, even when added in high concentrations; it is a comparatively major constituent of the extract, forming approximately 1 per cent of the dry leaf. Aspen-leaf extracts also contain small amounts of a polyuronide, and this, too, is a powerful deflocculating agent. The evidence suggests that other deflocculating agents are also present in aspen leaves. (C. Bloomfield.)

SOIL MICROBIOLOGY DEPARTMENT

H. G. Thornton

Miss Janet Findlater resigned her appointment on marriage, and left on 31 March 1955.

Dr. Margaret Brown was appointed to our permanent staff, and joined the Department on 1 October 1955.

Dr. I. L. Stevenson returned to Canada on 22 June after two years' research, for which he was awarded the PhD. degree. His place has been taken by Mr. E. A. Peterson, also from Bacteriology Division, Science Service, Ottawa, Ontario, who arrived on 30 May 1955 on a two-year Fellowship.

Dr. K. M. Pandalai worked in the Department for a few weeks during July and August 1955.

At the invitation of Professor E. B. Chain, Dr. N. Walker visited the International Centre for Research in Chemical Microbiology, Istituto Superiore di Sanità, Rome, where he worked for six weeks.

The Department has investigated various aspects of the ecology of the soil micropopulation.

The general purpose of studying the ecology of micro-organisms in soil is to gain knowledge that can be applied to discourage harmful organisms, such as those producing root disease, and to encourage those that are useful, whether as antagonists to plant pathogens or in producing available plant nutrients.

There are several ways in which the composition of the soil micropopulation can be modified. One is by the addition of materials that encourage the activity of certain groups of organisms. Thus certain types of green manuring are known to control some kinds of root disease. But this method is crude and uncertain in practice, while the factors involved are too complex for precise study. We need at this stage to follow the effects on the micropopulation of adding a definite compound to the soil and preferably one that is not naturally present and that is hence likely to be attacked by only a limited number of organisms. The chlorophenoxyacetic acids satisfy these requirements, and their persistence in soil is also of some practical interest.

Decomposition of Chlorophenoxyacetic Acids in Soil

When a first dose of 2 : 4-dichlorophenoxyacetic (2 : 4-D) or 2-methyl-4-chlorophenoxyacetic acid (MCPA) is added to fresh soil it disappears in a period of some weeks. Successive doses increase this rate of disappearance until 50 p.p.m. will disappear in 4 to 6 days.

Adaptation of the soil microflora to decompose the compound can be induced by as small an initial dose as 1 p.p.m. A considerable degree of cross adaptation can be produced; thus a soil adapted to decompose MCPA is thereby adapted to decompose 2 : 4-D and parachlorophenoxyacetic at enhanced rates.

This adaptation is no doubt due to the increase in the soil of organisms that can attack the compound; indeed, bacteria that can attack 2 : 4-D, MCPA, and parachlorophenoxyacetic acid have now been isolated and studied in pure culture. In the cases investigated it has been found that adaptive enzymes are concerned in decomposition of the compounds, so that when these are added to soil, enzyme adaptation must precede the differential increase of the specific organisms. Cross adaptation has also been demonstrated in pure-culture studies as well as in the natural soil.

Experiments, both in the laboratory and in the field, have shown that when a soil has become adapted to decompose 2 : 4-D or MCPA, it takes at least six months to lose this adaptation in the absence of any further addition of the compound. Thus the induced change in the micropopulation is remarkably persistent. This change no doubt involves the multiplication of organisms that attack the compound added and also of those that can attack the products of its decomposition. There is evidence that the two organisms principally studied by Warburg manometry do not break down 2 : 4-D or MCPA to completion, but leave end-products whose nature and effects on the soil population are as yet unknown. This work has been carried out by N. Walker and T. Steenson.

The Addition of Trichloroacetic Acid to Soil

Parts of some of the plots on Barnfield were treated in the spring with the herbicide trichloracetic acid at a rate of 20 lb./acre. Dr. Jane Meiklejohn and J. W. Millbank took soil samples from the treated and untreated areas of Plots 1N, 10 and 80 and examined these to see whether treatment with the compound had produced any persistent differences in the micropopulation. They found no differences in total microscope or plate counts of bacteria, in the numbers of Azotobacter or of *Clostridium pasteurianum*, or in the rates at which ammonia or nitrite were oxidized. This was about 8 weeks after the weed-killer was applied.

Clover Nodule Bacteria

A second method by which the soil population can be modified is by the introduction of an organism into the soil. This has been successfully practised in the case of legume inoculation, and a study of the factors here involved is important, not only to this practice but also to the problem of introducing other organisms into soil. Previous work has shown the importance of selecting a suitable strain that can infect the host plant in competition with other strains of lower efficiency in fixing nitrogen. Dr. Janina Kleczkowska has studied the effect of varying ratios of ineffective and effective strains on the growth of clover grown in a sand/vermiculite mixture and supplied with a nitrogen-deficient food solution. Two effective strains were used. One of these, ClF, known to be competitive with other strains, improved clover growth in a ratio of 1 to 1,000 ineffective bacteria and gave an increased effect with higher ratios. The second effective strain 2057 gave irregular results and little improvement in growth.

Experiments were also continued to test growth and survival of clover Rhizobium in soil and media of various pH. The strains

tested grew and survived for 6 weeks in liquid and agar medium, containing yeast extract at a pH range of 4·5–6·0, but in sterilized soil with or without yeast, strains grew and survived 6 weeks only at a pH of 5·7 or higher. At a lower pH none grew and all died within 2 weeks.

Rhizosphere Fungi

The roots of plants provide a micro environment, the rhizosphere, that is of obvious importance, and we have some knowledge of the bacterial flora of this region. Comparatively little is known of rhizosphere fungi other than pathogenic forms. E. A. Peterson has commenced a study particularly of the fungi of the rhizospheres of clover from clover-sick and healthy soil from Woburn. This work is in its early stages, but preliminary results suggest that there are differences in fungal population of the clover rhizosphere from healthy and from clover-sick soil.

Azotobacter and Clostridium

The organisms responsible for non-symbiotic nitrogen fixation in soil have always been a problem. The present practice of fallowing successive stages of Broadbalk each year and the observation that this fallowing particularly benefits the plots not receiving nitrogen dressings suggests the use of this field to obtain data on the relation of fallowing, fertilizer treatment and crop yield to the number of nitrogen-fixing organisms. Jane Meiklejohn has commenced a survey of the content of Azotobacter and of *Clostridium pasteurianum* from various Broadbalk plots. Data so far obtained show that numbers of Azotobacter are higher in the fallow than in the cropped sections so far examined, but counts made by an improved method specific for Azotobacter gave very low numbers ranging up to only 2,000 per gram. These were much exceeded by the estimated numbers of Clostridium, whose importance in nitrogen fixation may be greater than has usually been supposed.

Some soils from the Bukoba district of Tanganyika were also examined for nitrogen-fixing organisms and yielded the tropical form Beijerinckia. Two of these samples appeared to fix nitrogen poorly owing to molybdenum deficiency.

Jane Meiklejohn and Dr. K. M. Pandalai made experiments on the associated growth of Azotobacter and Nitrosomonas in synthetic liquid media. In media with a low sugar content the Azotobacter grew for a short while only, and then appeared to secrete ammonia that was oxidized by the Nitrosomonas. If this secretion occurs in field soil it could result in the loss of fixed nitrogen by leaching.

Bacteriophage

The study of the interaction of bacteriophage and Rhizobium has been continued by Janina and A. Kleczkowski. Following on their study of the effects of ribonuclease and chymotrypsin on the interaction, they have investigated that of clupein.

When present at concentrations of 0·02–0·05 per cent in the liquid nutrient medium used to cultivate nodule bacteria, clupein rapidly killed the bacteria, slowly inactivated phage, and prevented phage

and bacteria from combining, or, if added when phage–host combination had already taken place, interrupted further stages of phage–host interaction. At a concentration of 0·0016 per cent clupein acted bacteriostatically, and slowed down phage multiplication but did not stop it.

Trypsin and chymotrypsin hydrolyse clupein, trypsin breaking about twice as many peptide bonds as chymotrypsin. At a concentration corresponding to 0·02–0·05 per cent clupein, the peptides produced by chymotrypsin acted bacteriostatically in the liquid nutrient medium; the peptides inactivated phage much more slowly than did intact clupein, and they inhibited phage multiplication by interfering with the combination between phage and host. When added after phage and bacteria had combined, the peptides did not interfere with further stages of phage–host interaction. The smaller peptides produced by trypsin had no effect on host bacteria, phage, or phage–host interaction, neither did any of the constituent amino acids of clupein when used singly at a concentration of 0·05 per cent.

European Foul Brood of the Honeybee

F. A. Skinner has made a further study of the varied bacterial flora which develops in the gut of the bee larvæ suffering from European Foul Brood.

"Docking Disorder" of Sugar Beet

In the Docking district of Norfolk poor growth of sugar beet is associated with deformation of leaves, together with abnormal root growth in the adult plant, and with less clearly specified seedling damage. The cause of this disorder is not known, but it was suggested that the general soil microflora might be concerned, perhaps in connection with the production of some toxic substance. F. A. Skinner, after discussion with the National Agricultural Advisory Service, examined seedlings in the field and others grown in pots of Docking soil at Rothamsted, but was unable to attribute any particular seedling symptom to growth in disease-producing soil. He also examined the possibility that some toxic substance caused the damage. Soil samples from a badly affected area at Docking were collected and extracts made from these by various methods. The effects of these extracts on the respiration of sugar-beet root tips and on the rate of root extension were tested, but no evidence of any toxic effect was found.

BOTANY DEPARTMENT

D. J. Watson

G. H. King was awarded the National Diploma in Horticulture; he is the first member of the assistant staff to obtain this qualification by part-time study. K. J. Witts joined the Department in May.

Plant Nutrition

Interaction between iron and micronutrient elements (K. Warington)

Chlorosis induced by excess vanadium in peas and soybeans grown in solution culture has been shown to be offset by high iron supply more readily if both elements are supplied in the same solution than if supplied separately in successive time intervals (*Rep. Rothamst. exp. Sta. for 1954*, p. 65). Similar results have now been obtained with molybdenum. They indicate that the interaction between iron and molybdenum or vanadium takes place, partly at least, outside the plant in the nutrient solution.

In these experiments the precipitation of iron that usually occurs in culture solutions was delayed for at least one day, and often longer, by addition of high concentrations of molybdenum when the initial pH was 4·6, but not when it was 6·6, whether or not plants were growing in the solution. To test whether the availability of iron in a complete culture solution is affected by molybdenum or vanadium, plants showing chlorosis induced by iron deficiency were transferred to solutions containing high iron concentrations with or without molybdenum or vanadium in high concentrations at varying times after the solutions were prepared. In the vanadium experiments on peas, the rate of recovery from chlorosis and the iron content of the shoots of the control plants were not affected by allowing the solutions to stand for 1 to 4 days before use, but the iron content of the roots was reduced after 2 days' standing. Vanadium had no effect on recovery from chlorosis nor on the iron content of shoots or roots. However, the vanadium contents of both shoots and roots decreased with increase in the interval between making up the solution and transferring the plants to it, and this suggests that vanadium interacts with some constituent of the solution, although it does not appear to affect the availability of iron.

In the molybdenum experiments on peas and soybeans, the solutions were allowed to stand up to 9 days before use, and molybdenum was supplied as sodium or ammonium molybdate. With increase in the standing time, the chlorotic test plants developed a green colour more slowly, and the iron content of the shoots of peas, but not soybeans, and of the roots of both species, was decreased. Precipitation of iron was delayed from 1 to 4 days whenever molybdenum was given, and the drift towards a higher pH was retarded. The rate of recovery of a green colour was unaffected by molybdenum if the solutions were used within 7 days of preparation, but with longer standing times recovery was more rapid when molybdenum was supplied, especially as the ammonium salt. Addition of

molybdenum did not alter the iron content of the shoots, but increased that of the roots of both peas and soybeans.

These results suggest that molybdenum increases iron uptake by delaying precipitation of iron in the culture solution. Experiments have been done to investigate whether the delayed precipitation is a direct effect of molybdenum or an indirect result of slower change in pH, but the results are not yet complete.

Nutrient uptake by excised roots (E. C. Humphries)

Many attempts have been made to use leaf analysis as a measure of the supply of mineral nutrients from the soil, and as a guide to the fertilizer requirements of crops, but the method has not been generally successful. It is probable that the root reflects more precisely the mineral status of the soil in which it is growing than any other organ of the plant. Previous work on root systems excised from plants grown in solution culture has shown that the rate of uptake of a nutrient element depends on the concentration of that element in the roots and on the reducing sugar content of the roots, but is independent of the concentrations of other nutrient elements. Although the mineral composition of the root may itself be useful for diagnosis of the nutrient status of the soil, it is possible that the rates of absorption of nutrients in standard conditions by root systems removed from the soil may provide more sensitive tests of deficiencies in the soil nutrient supply.

Preliminary experiments were done to ensure that root systems recovered from the soil with as little damage as possible were capable of absorbing nutrients in laboratory conditions. Samples of wheat roots were then taken from a number of plots of Broadbalk field to test whether roots grown in the field with a wide range of nutrient supply show corresponding variation in ability to absorb nutrients. The roots were washed, centrifuged to remove surface moisture, and put in an aerated complete nutrient solution at 25° C. for 4 hours. Samples were taken before and after the absorption period for chemical analysis to determine the amounts of nutrients absorbed.

With the same purpose and also to investigate whether varietal differences in yield of barley (see p. 76) depend on the capacity for nutrient absorption of the roots, nutrient uptakes by excised root systems of Plumage-Archer, Kenia, Proctor and Herta barleys were compared in standard laboratory conditions. Roots were taken either from plants grown in pots of a nutrient-deficient soil, with or without addition of a complete fertilizer, at four stages of growth, or from plants grown in solution cultures with varied concentrations of N, P and K. Chemical analyses of the 1,200 samples collected in these experiments are still in progress.

Nutrient uptake from leaf sprays (G. N. Thorne)

Studies of the factors affecting the rate of absorption of ^{32}P through leaves and its rate of translocation to other parts of the plant (*Rep. Rothamst. exp. Sta. for 1954*, p. 67) were continued. When small swede plants were sprayed on one leaf with a ^{32}P-labelled phosphate solution, more phosphorus was absorbed in 3 days by plants placed under transparent or opaque covers than by uncovered plants. Most of the additional phosphorus remained in the sprayed leaf of the darkened plants, but in the illuminated ones

it was translocated to the rest of the leaves and roots. In another experiment, plants under a transparent cover absorbed more ^{32}P in 6 days than shaded plants, and uptake in the dark was increased by spraying the ^{32}P treated leaf with 10 per cent sucrose solution; this additional ^{32}P moved to other leaves but not to the root. These results suggest that translocation of P from the sprayed leaves is dependent on simultaneous movement of carbohydrate.

Covering plants may increase phosphorus uptake by raising the humidity of the air. Uptake by plants placed under a cover with a drying agent was less than by plants under a cover where the air was kept moist, but even where a drying agent was used more ^{32}P was absorbed than by uncovered plants. Absorption of ^{32}P by French bean leaves from a concentrated spray applied to one primary leaf, or one leaflet of the third leaf, was greater than that from twice the volume of a spray of half the concentration applied to both the primary leaves or to 2 leaflets of the third leaf. Absorption from the concentrated spray appeared to be faster than from the dilute spray; the difference in amount absorbed was greater after 3 days than after 6 days. More ^{32}P was absorbed from spray and translocated by the third leaf than by the primary leaves.

The field experiment on the effect of combining a nitrogenous spring top-dressing for wheat with a weed-killer spray (*Rep. Rothamst. exp. Sta. for 1954*, p. 67), was repeated. Spray application of N increased the yield of grain, straw, chaff and weeds slightly less than application as fertilizer to the soil. The amounts of Mayweed (*Matricaria inodora*) and Knotgrass (*Polygonum aviculare*) were reduced by 2 : 4-D, but the yield of wheat was unaffected. The effect of 2 : 4-D on weeds was independent of the method of nitrogen application, but in this and the previous experiment the recovery of nitrogen in the crop from spray application was about half that from fertilizer applied to the soil. The reason for the low recovery of N from sprays is not known, but it makes the combination of a spring top-dressing with a weed-killer spray undesirable.

In a previous experiment to test whether sprays of organophosphorus insecticides affect plant growth independently of control of insect damage (*Rep. Rothamst. exp. Sta. for 1953*, p. 70), some statistically significant increases in yield by spraying with insecticide or solutions supplying equivalent amounts of inorganic phosphorus were found in plants that already had a high phosphorus supply from the soil. As these effects have no obvious rational explanation, it seems probable that they were due to chance, so the experiment has been repeated. Brussels-sprouts plants grown in pots were sprayed with "Systox", "Pestox III" or equivalent sodium phosphate solutions. The plants were larger than in 1953 and retained more spray. The total phosphorus content of plants grown in soil deficient in phosphorus was increased by the "Pestox III" spray and by the equivalent sodium phosphate solution, which had more than five times the phosphorus content of the "Systox" spray. None of the sprays increased dry weight; "Pestox III" slightly reduced the total dry weight of plants grown with a high phosphorus supply to the roots. The results give no evidence that phosphorus-containing insecticides are beneficial to plants, either by virtue of the small amount of phosphorus that they supply or by any specific effect on growth.

Weed Studies

Wild Oats (J. M. Thurston)

In the fifth year of the field experiment on survival of wild oats sown at two depths in October 1950, on plots that subsequently received different cultivations (*Rep. Rothamst. exp. Sta. for 1954*, p. 67), all the plots were treated alike; they were dug by hand at the end of March and in October to encourage germination of surviving viable wild oat seeds, and to control other weeds. No more *Avena ludoviciana* seeds germinated, but a few *A. fatua* seedlings appeared on plots of all treatments. Where the seed was sown 6 inches deep on plots that had only surface cultivations for 4 years, there were more *A. fatua* seedlings than elsewhere, indicating that prolonged undisturbed burial induced dormancy in some seeds. The number of seeds germinating in 1955 was a very small fraction of those sown in 1950, the great majority of which have still not produced seedlings.

In the experiment in Hoosfield comparing the effect of winter and spring cereals on the establishment and growth of *A. fatua* (*Rep. Rothamst. exp. Sta. for 1954*, p. 68) barley was sown in spring on all plots, to compare the numbers of viable seeds remaining after the different crops in 1953 and 1954. The mean numbers of wild oat seedlings per square yard in 1955 were 4·9 after winter rye, 2·9 after winter wheat, 2·2 after winter barley, 1·5 after spring barley and 0·6 after fallow. The total was only about one-quarter of the number that appeared in 1953, and the treatment differences in 1953 and 1954 tended to be reversed in 1955. Thus, fewer wild oat plants appeared in winter wheat and rye in 1953 and 1954 than in barley or fallow, but in 1955 there were many more in barley after winter rye than elsewhere. This suggests that cropping with winter rye may have prolonged the dormancy of some of the wild oat seeds. The barley crop after fallow was much heavier than on other plots, and the growth of the wild oat plants was correspondingly reduced by more intense competition.

Soil samples taken in May from the plots of the experiment in Northamptonshire on survival of wild oat seeds under temporary ley (*Rep. Rothamst. exp. Sta. for 1954*, p. 69) showed that after one-year ley the number of potentially viable seeds was nearly halved, but there were still about 6 million per acre. The species of many of the seeds could not be identified, because of rotting of the husks, but there is no doubt that the number of viable seeds of both *A. fatua* and *A. ludoviciana* was greatly decreased since the previous year.

In the experiment at Boxworth Experimental Husbandry Farm, plots ploughed in autumn 1954 after 4 years under ley produced an average of 2 plants per square yard in May 1955, compared with 7·5 on plots ploughed and counted one year earlier. Unfortunately, the numbers and species of seeds in the initial infestation of this experiment and the numbers capable of germination in the earlier years are not known. A similar experiment was started at Rothamsted in spring 1955 on a field that had an average of 9 plants of *A. fatua* per square yard at the time of sowing of the ley. Plots will be ploughed up annually and cultivated to encourage germination of wild oat seeds so that the infestation surviving after varying periods under ley can be measured.

An experiment on competition between *Avena ludoviciana* and wheat, barley or rye sown together in pots in autumn gave similar results to that done in 1954 on *A. fatua* competing with barley or wheat sown in spring (*Rep. Rothamst. exp. Sta. for 1954*, p. 69). As before, barley was a more effective competitor than wheat; rye was intermediate. When the wild oats were sown two weeks after the cereal, they produced only 60 per cent of the number of seeds produced by plants sown at the same time as the cereals. No inhibitory effect of rye on the growth of wild oat seedlings was found.

Freshly-harvested seeds of 10 selections of *A. ludoviciana* and 6 of *A. fatua*, of distinctive types not found at Rothamsted (*Rep. Rothamst. exp. Sta. for 1952*, pp. 69 and 71), were sown in soil in a cool glasshouse in September. In 7 selections of *A. ludoviciana* most of the first seeds in the spikelets germinated within one month, and all within two months, and many of the second seeds also germinated. This lack of dormancy supports the theory that these types are hybrids between *A. ludoviciana* and non-dormant cultivated oats. The other 3 selections shewed much longer periods of dormancy in the same period, 0–7 per cent of the *A. fatua* seeds germinated, and a few more seedlings appeared in the third month. Thus these types resemble the Rothamsted *A. fatua* in showing high dormancy.

Germination tests were made on seeds from two trials in which wild oats were sprayed with maleic hydrazide after the panicles emerged to prevent the formation of viable seeds. In a field trial done by the National Agricultural Advisory Service in Dorset, $1\frac{1}{2}$ lb. maleic hydrazide per acre decreased the number of viable seeds by 45 per cent, but germination of barley grain from the crop in which the wild oats grew was decreased by 28 per cent, and many of the seedlings were deformed. Application at $\frac{3}{4}$ lb./acre had no effect on the barley, but decreased the number of viable wild oat seeds by only 17 per cent. Pot-grown plants of *A. fatua* and *A. ludoviciana* were sprayed with maleic hydrazide by the Unit of Experimental Agronomy, Oxford, at three stages of development ranging from just before the panicles emerged until they were fully expanded. The later sprayings decreased the number of viable seeds to less than one-third of those produced by unsprayed plants, and a smaller proportion of the surviving seeds were dormant.

Other species (J. M. Thurston)

In the wet summers of 1953 and 1954, *Polygonum persicaria* became abundant in one field of Rothamsted, and some work has been done on dormancy of its seeds. High temperatures favoured germination; more seeds germinated at 27° C. than at laboratory temperatures, or at 7° C., or with alternations between 27° C. and lower temperatures. Germination percentage and rate of germination were increased by chipping or removing the seed coats, or by soaking in tap-water or 2 per cent KNO_3 solution before sowing. Dormancy decreased after 3 or 4 months' storage in the laboratory.

Broadbalk field (K. Warington and J. M. Thurston)

Soil samples taken from all sections of five plots of Broadbalk field were reduced in bulk by washing through sieves, and the residues put in pans in the glasshouse, to determine the numbers of viable weed seeds present by counting and identifying the seedlings as they

germinate. The results will show what changes have occurred in the weed-seed population since the last sampling in 1945, and will also provide a base line to measure changes in the weed flora that follow reversion in 1956 to continuous wheat growing on part of Section I after 25 years of the fallowing cycle.

Physiological Effects of Virus Infection

Effect of infection on the respiration rate of tobacco leaves (P. C. Owen)

The effect of infection with tobacco mosaic virus (TMV) on the respiration rate of tobacco leaves has been shown to vary with environmental conditions, with the time elapsed since inoculation, and with the stage of development of the leaves used (*Rep. Rothamst. exp. Stn. for 1954*, p. 70). In a new series of experiments leaves of tobacco plants inoculated with TMV were divided into three groups: (*a*) the inoculated leaves; (*b*) younger leaves present at the time of inoculation but not themselves inoculated; (*c*) leaves formed since inoculation, and the respiration rate of each group was compared with that of similar leaves from healthy plants during the period between inoculation and development of systemic infection. The respiration rate of inoculated leaves was increased above that of the controls within one hour of inoculation, long before virus multiplication can be detected. The proportional increase in respiration rate remained approximately constant for three weeks until the plant showed systemic symptoms, at which time inoculated leaves contained their maximum amount of virus, and the respiration rate then fell below that of healthy controls. This implies that the increase of respiration rate is not related to the quantity of virus in the leaf; it may reflect changes in infected cells preparatory to virus synthesis. The decreased respiration rate per g. dry weight after three weeks is possibly due to accumulation of material inactive in respiration.

There was never any detectable effect of infection on the respiration rates of non-inoculated leaves in group (*b*). Although symptoms appeared on these leaves, they probably did not contain appreciable amounts of virus. Their metabolism was evidently not affected in the same way as that of the inoculated leaves during the establishment of systemic infection in the plant. The respiration rate of leaves formed on infected plants after inoculation (group (*c*)) was 10 per cent below that of comparable healthy leaves. Presumably all the cells of these leaves were fully infected before their respiration was measured, and had completed the initial metabolic change that causes the increased respiration of inoculated mature leaves. The total virus content of systematically infected leaves accounts for about 10 per cent of the dry weight, and if it makes no contribution to respiration, it could account for the 10 per cent reduction in respiration rate per g. dry weight.

Severe etch virus in tobacco leaves attains only about one-thousandth of the concentration reached by TMV, but it produces very severe symptoms. The effect of this virus on the respiration of tobacco leaves is therefore being compared with that of TMV. Preliminary experiments showed that the immediate effect of infection is smaller than that of infection with TMV, and measurements are being made at later stages of infection.

Growth Analysis

Effect of time of application of nitrogenous fertilizer and of mildew infection on yield of wheat (G. N. Thorne and F. T. Last, Plant Pathology Department)

The data from the pot experiment done in 1954 (*Rep. Rothamst. exp. Sta. for 1954*, p. 71) have now been examined, but the experiment was unsuccessful because the effects it was designed to analyse did not occur. The mildew infection was not severe enough to affect the final yield significantly, and had only small and temporary effects on growth early in the season. Contrary to previous experience with field crops and pot cultures, nitrogenous fertilizer applied at the time of ear emergence had a much smaller effect on grain yield than when applied at sowing or in April. The reason for this is not clear. The late N application increased leaf area after ear emergence more than the earlier applications, but the extra leaf area was apparently ineffective in adding to grain yield, possibly because it was produced mainly by increasing the length of life of leaves on sterile tillers. The plants that had no nitrogenous fertilizer were very N-deficient, and this may account for the lack of response in grain yield to the late N application, because other experiments suggest that late N applications are less effective on plants that previously have had a very low N supply.

Varietal differences in yield of barley (G. N. Thorne, S. A. W. French, K. J. Witts and F. V. Widdowson, Chemistry Department)

Proctor barley, bred by Dr. G. D. H. Bell at Cambridge, is the successful outcome of an attempt to combine the good malting qualities of the old varieties Plumage-Archer and Spratt-Archer with high yield. In field trials it has yielded on the average some 15 per cent more grain than the old varieties, and has proved to be comparable in yield with the best Scandinavian varieties, such as Herta. The extra grain yield of Proctor compared with Plumage-Archer must be the result of physiological changes induced by breeding and selection, the nature of which is not yet known. Experiments were therefore started to investigate by growth analysis the physiological basis of the differences in grain yield between Proctor, Herta and Plumage Archer. The three varieties were grown in a field experiment, with and without nitrogenous fertilizer, and samples were taken at fortnightly intervals from soon after germination until harvest to determine dry weight, leaf area, plant and shoot number, and other appropriate measures of growth.

At the end of the experiment part of each plot was harvested by combine, giving the following exceptionally high mean yields :

Grain, cwt./acre

	Plumage-Archer	Proctor	Herta	S.E.
No N	43·9	51·0	48·5	1·00
0·5 cwt.N/acre ..	40·6	52·7	55·6	
Mean	42·3	51·8	52·0	0·71

The results show the expected superiority of Proctor and Herta over Plumage-Archer; at the higher N level it was partly attributable to lodging of Plumage-Archer. The same varieties were grown in

a pot-culture experiment with two rates of nitrogen supply. The variety Kenia was also included because Proctor originated from a Kenia × Plumage-Archer cross. In the pots, Proctor was superior in grain yield to Herta and Plumage-Archer at the low N level, but with high N supply Herta gave the highest yield. The chief object of this experiment was to find out whether the varieties differ in respect of the contributions made by photosynthesis in different parts of the plant to the total dry matter entering the grain. The ears of some plants were covered with opaque shades, other plants had the awns removed or the lower leaves and stems shaded, and the effect of preventing photosynthesis in these parts was measured by the loss of dry matter in comparison with untreated plants. Measurements of growth before ear emergence were also made as in the field experiment. Samples were kept from both experiments for chemical analysis to determine whether there were varietal differences in nutrient uptake and distribution. Statistical analysis of the growth data and chemical analyses are not yet completed.

Effect of varying soil moisture deficit on plant growth (P. C. Owen)

A series of experiments was done in the glasshouse to determine whether variations of soil moisture content within the range from field capacity to near wilting point, but avoiding wilting, affect plant growth and dry-matter yield. Three water regimes were compared in which the soil moisture content was allowed to fall repeatedly from field capacity to three different levels before the soil was saturated again. Broad beans, sugar beet and lettuce were grown. There were no significant effects on dry weight in any of the crops. The water content of the lettuce, but not of the other crops, was decreased by the driest conditions. In the sugar-beet crops there were no detectable effects on net assimilation rate or leaf area.

Some preliminary work was done on effects of irrigation on plant growth with material from the sugar beet crop of the Woburn Irrigation Experiment. The unirrigated plots and the plots that were irrigated throughout the growth period, with and without additional nitrogenous fertilizer, were used, and only three samplings at fortnightly intervals were possible because most of the crop had to be kept for estimating yield at the final harvest. No rain had fallen for 3 weeks before the first sampling on 27 July, and the estimated water deficit on the unirrigated plots was 4 inches; on the other plots it was kept below 1 inch by appropriate irrigation. The dry weight and leaf area index (L; ratio of leaf area to land area) of the irrigated crop were already much above those of the unirrigated crop. There was no rain in the following fortnight, and the effects of irrigation were greatly increased. In the interval between the 1st and 2nd samplings relative leaf growth rate was lower on the unirrigated plots than on the irrigated ones, so that at the 2nd sampling, L was more than doubled by irrigation. Net assimilation rate (E) was also lower on the unirrigated plots, and this, combined with the lower L, gave a much smaller dry-weight increment than on the irrigated plots. These results confirm pot-culture experiments by other workers in showing that severe and prolonged water stress decreases yield by decreasing both net assimilation rate and leaf area.

In the next fortnight before the 3rd sampling, 0·6 inches of rain

fell, but the estimated water deficit on the unirrigated plots increased to nearly 6 inches. Nevertheless, the unirrigated plants had a higher relative leaf-growth rate than the irrigated plants in this period, so that at the 3rd sampling the effect of irrigation on L was proportionally much less than at the 2nd sampling, causing an increase of only 60 per cent instead of 120 per cent. An even more surprising result was that E for the unirrigated plants was nearly three times that of the irrigated plants, so that in spite of their smaller L they produced a larger dry-matter increment. The mean values of E in g./sq. m. per week for the two periods were :

	27 July–10 Aug.	10–24 Aug.
Not irrigated	53	96
Irrigated	83	34
S.E.	±8·3	±14·5

Similar results were found at both levels of N supply. The reason for the decrease in E between the first and second periods on the irrigated plots is not known. Presumably, it was due to change in some external factor other than water supply; it cannot be attributed to the higher L of the irrigated plots, because the greatest value of L on the irrigated plots with high N supply at sampling 3 was only 3, and variation of L over the even wider range between 1 and 5 had much smaller effects on E of sugar beet than those shown above (*Rep. Rothamst. exp. Sta. for 1954*, p. 72).

The results suggest that rainfall after prolonged drought in amounts small in comparison with the soil moisture deficit may, temporarily at least, have very large effects on leaf growth and photosynthetic efficiency, perhaps through direct uptake of water by the leaves. The work needs to be repeated, and the duration of the effect of small amounts of rain determined. If the results are confirmed they may have an important bearing in the economic use of irrigation water.

An attempt to increase yield by controlling leaf area index (D. J. Watson, S. A. W. French and G. H. King)

Previous work has shown that the net assimilation rate (E) of a kale crop decreases as leaf area index (L; leaf area per unit land area) increases (*Rep. Rothamst. exp. Sta. for 1954*, p. 72). Consequently the rate of dry matter production per unit area of land increases with increase in L, reaching a maximum when L lies between 3 and 4, and falling again at higher values of L. The total dry matter production per unit area of land over the whole growth period, i.e., the dry matter yield, should therefore be increased if L were held near the optimum and not allowed to rise above it, and this could be accomplished by repeatedly removing an appropriate fraction of the plant population.

This procedure was applied to a kale crop grown on a fertile soil with a liberal fertilizer dressing to produce as large leaf area as possible. Successive samplings showed that by the middle of July L had risen to approximately 4, and on half the plots a quarter of the plants were removed to reduce L to about 3. On the remaining plots the crop was left unthinned. There was little growth in leaf area during the following 3 weeks because of lack of rain, and at the beginning of August and again in September the crop was irrigated

with an overhead spray. By the end of August L for the unthinned crop had increased nearly to 6. On the thinned plots the thinning was repeated three times in August and early September, L being reduced from near 4 to about 3 on each occasion. Nearly two-thirds of the plants initially present were removed in the four thinnings. The unthinned plots, and the remaining crop on the thinned plots, were harvested at the end of September. Measurements of E based on samples taken fortnightly, usually at the same time as the thinning, showed in accordance with the previous results that E was consistently higher for the thinned crop, where L fluctuated between 3 and 4, than for the unthinned crop, where L rose to between 5 and 6 in August and September. However, the total yield of dry matter on the thinned plots, including the plants removed at the successive thinnings, was only about 6 per cent greater than on the unthinned plots, and the difference was not significant. The reason may be that the thinning was sometimes too severe, because the preliminary samplings to estimate L, from which the proportion of plants to be removed was determined, gave erroneously high values, and in some plots L was reduced to about 2·5. The drought in July and August may also have affected the result. Less drastic thinning and more accurate control of L might give larger increases in dry matter production, but even if the procedure is successful there are many obvious difficulties in the way of its practical application.

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

Marjorie Byers and A. J. Clarke joined the department, and M. V. Tracey has been given leave of absence to accept a Royal Society and Nuffield Foundation Commonwealth Bursary. He will be working in the Wool Textile Laboratory of the Commonwealth Industrial and Scientific Research Organization at Melbourne. Five members of the department attended the Third International Congress of Biochemistry in Brussels, and N. W. Pirie attended the World Symposium on Applied Solar Energy in Arizona.

Plant Enzymes

Ribonuclease (W. S. Pierpoint)

Work on the characterization of leaf ribonuclease has been continued. It has proved possible to obtain, by a process of gradient elution chromatography on a cation-exchange resin, a dilute but purified preparation of the enzyme free from phosphatase activity against ATP, metaphosphate and β-glycerophosphate. This confirms the previous suggestion that the enzyme, like the pancreatic ribonuclease, is a specific phosphodiesterase.

A number of properties of the enzyme have been described and a number of compounds tested against it as possible inhibitors. A specific inhibitor of ribonuclease could possibly be of great help in the isolation of unaltered nucleoproteins from plant leaves and in elucidating the physiological role of the enzyme. The compounds tested included some antiviral compounds which are structural analogues of the naturally occurring purines and pyrimidines, and a number of antibiotics which inhibit protein synthesis. However, no specific inhibition was observed.

Metaphosphatase (W. S. Pierpoint)

One of the enzyme activities present in the pea-leaf extracts which is difficult to remove from the ribonuclease is metaphosphatase. Metaphosphate itself has not been detected in the higher plants, although it seems to form a very large percentage of the total phosphorus of some moulds and fungi, and to be very active metabolically. A number of observations have therefore been made on the metaphosphatase activity of the pea extracts.

Some evidence has been obtained which suggests that the metaphosphatase activity is associated with an unspecific acid phosphomonoesterase. Thus the ratio of activity towards metaphosphate and β-glycerophosphate was found to be constant in a wide range of pea-leaf extracts, and is not significantly altered by various protein fractionation treatments, including precipitation, heat denaturation and adsorption. Attempts were made to prepare a purified sample of this enzyme by gradient elution chromatography on an ion-exchange resin. The enzyme is eluted, however, in two distinct peaks, both with the same ratio of metaphosphatase to glycerophosphatase activity. Whether these peaks represent

different enzymes or are different forms of the same enzyme has not been determined.

Amine oxidase and auxin formation (P. J. G. Mann)

There is much evidence that 3-indolylacetic acid (IAA) is formed in the plant from tryptophan, but the metabolic pathway is not yet established. It has been suggested that the route is by way of tryptamine and 3-indolylacetaldehyde (IAc) or 3-indolylpyruvic acid and IAc. We have already reported preliminary evidence suggesting that the oxidation of tryptamine to IAc is catalysed by plant amine oxidase. This work has been continued, and it has now been established (by A. J. Clarke) that the primary oxidation product is IAc. It has also been shown that the enzyme catalyses the oxidation of 5-hydroxytryptamine. There is evidence that this compound, as well as tryptamine itself, occurs in plants. A method has been worked out for the estimation of IAc. This depends on the oxidation of IAc to IAA with silver oxide. The IAA formed is then estimated. Using this method, the conditions favouring the accumulation of IAc in the enzyme-catalysed oxidation of tryptamine have been investigated. At pH 7 the IAc found is about 80 per cent of theory, provided the reaction time is short and the tryptamine concentration is low. Under alkaline conditions the yield is lower, possibly owing to polymerization of the aldehyde. At high tryptamine concentrations the low yield appears to be due to the combination of the aldehyde with unchanged tryptamine.

Having thus established that the first stage in the postulated pathway from tryptamine to IAA is catalysed by plant amine oxidase, we have begun a study of the second stage—the oxidation of IAc to IAA. Much of the previous work on this reaction has been done with a heterogeneous material containing only 2 per cent IAc made by treating tryptophan with ninhydrin or isatin or by the use of plant extracts containing IAc. While a chemical method of synthesis is now available by which pure IAc can be obtained, the procedure is difficult, and for this reason, and also because of the instability of the compound, the enzymic method of preparation has obvious advantages. Work in this department has already shown that the oxidation of phenylacetaldehyde is catalysed by plant saps. The system in pea-seedling sap catalysing this reaction was found to consist of a peroxidase together with a thermostable factor which can be partially replaced by manganous ions. It has now been shown that the oxidation of IAc is catalysed by plant saps and by peroxidase, particularly in presence of Mn^{2+}. By analogy with the phenylacetaldehyde reaction 3-indolylaldehyde would be expected as the product of such oxidation. However, small amounts of IAA accumulate during the oxidation, despite the fact that the plant saps catalyse the oxidation of IAA. It is possible therefore that a significant part of the IAc is oxidized to IAA either by the peroxidase system or by another system as yet unidentified.

Amine oxidase and alkaloid formation (A. J. Clarke and P. J. G. Mann)

We have reported that the oxidation of putrescine and cadaverine, catalysed by plant-amine oxidase, results in the formation of Δ′-pyrroline and Δ′-piperideine compounds. It was suggested that

these ring compounds are formed by spontaneous cyclization of the aldehydes (γ-aminobutyraldehyde and δ-aminovaleraldehyde), or of the aldimines, which are the probable products of the enzyme-catalysed reactions. The suggestion has been made that, *in vivo*, the only enzymatic reactions directly concerned in the formation of certain pyrrolidine and piperidine alkaloids are those producing γ-aminobutyraldehyde and δ-aminovaleraldehyde and that the alkaloids result from the spontaneous condensation of these aldehydes with plant metabolites. If alkaloids are waste products of metabolism it seems likely that they might be formed by such a non-specific mechanism. We have therefore begun a series of experiments to test whether alkaloids are formed when the amine oxidase-catalysed oxidation of putrescine or cadaverine is carried out in the presence of the appropriate reactive methylene compounds.

The enzyme-catalysed oxidation of putrescine and cadaverine takes place without CO_2 formation; however, with acetoacetate or acetonedicarboxylate present in the reaction mixture the O_2 uptake is accompanied by a CO_2 output. The CO_2 arises from the reactive methylene compound, the concentration of which decreases during the reaction. This is not a simple decarboxylation of these compounds. Thus acetoacetate gives acetone on decarboxylation, but only traces of acetone are found in the reaction mixture, and there is little or no CO_2 output if the amine is omitted from the reaction mixtures or if boiled enzyme is used in the complete reaction mixtures. These results suggest that the CO_2 arises from a reaction between the reactive methylene compounds and the products of the amine oxidase reaction. In reaction mixtures containing both amines and reactive methylene compounds the Δ′-pyrroline and Δ′-piperideine compounds, which are the products of the oxidation of the amines, do not accumulate. New compounds are present which resemble pyrrolidine and piperidine. The results therefore suggest that condensation has taken place between the oxidation products of the amines and the reactive methylene compounds. Such condensations should result in the formation of norhygrine and norcuscohygrine from putrescine and *iso*pelletierine from cadaverine. Further chemical evidence is required to establish conclusively the nature of the products.

Manganese oxidation in the pea plant (Pisum Sativum, L.) (R. H. Kenten and P. J. G. Mann)

It has been suggested that the physiological effects of manganese may, in part, be due to its capacity for valency change. We have previously shown that Mn^{2+} is oxidized by peroxidase systems and by illuminated chloroplasts and have reported the results of preliminary experiments demonstrating the accumulation of higher oxides of manganese in the stems of pea plants grown in water culture at high Mn^{2+} concentrations. This work on *in vivo* manganese oxidation has been continued. A method of extracting the higher oxides of manganese from the plant stems has been worked out. The tissue was washed first with orthophosphate to remove interfering substances, then the manganese higher oxides were dissolved in pyrophosphate and estimated spectrophotometrically. It was only possible to demonstrate accumulation of higher oxides of manganese in the plant stems under conditions of manganese

toxicity. Thus the lowest concentration of manganese in the culture solution with which such accumulation could be clearly demonstrated was 22 p.p.m. Under conditions of severe manganese toxicity (110 p.p.m. Mn^{2+} in the culture solution) relatively large amounts of higher manganese oxides accumulated in the tissue equivalent to 100–200 μg. Mn^{3+}/g. fresh weight. We have shown that with peroxidase systems the oxidation *in vitro* takes place with physiological concentrations of Mn^{2+}. It is probable therefore, that *in vivo*, under normal conditions of manganese supply, the oxidized manganese is reduced by plant metabolites as fast as it is formed. This would involve the manganese in an oxidation–reduction cycle. Under conditions of manganese toxicity, part of the oxidized manganese escapes reduction and accumulates in the plant tissues.

Enzymes of bracken (R. H. Kenten)

Work has continued on the enzymes of bracken, and attention has been largely confined to the enzyme thiaminase. This enzyme is present in bracken, but has been reported absent from a large number of species of higher plants. A study of the inhibitors and substrate specificity of this enzyme may lead to the development of specific bracken-killing agents. For this work thiaminase preparations have to be made, and a simpler method for estimating thiaminase activity than that used hitherto would be valuable. Some progress along these lines has been made. The estimation of thiaminase activity involves the determination of small quantities of thiamine. As the known methods are subject to interference from a variety of substances, it is usual to separate the thiamine from other materials by absorption and elution from a column of suitable absorbent. Attempts to modify an existing method to avoid this time-consuming step have been partially successful, and we can now obtain reasonable results with some partially purified thiaminase preparations. It is of interest that this modified method was satisfactory with crude thiaminase preparations obtained from young bracken fronds, but failed with similar preparations from older fronds. While it is known that methods found to be satisfactory with one species of plant may not be suitable with another, it is not generally recognized that a similar situation may exist with tissues from the same species of plant in different physiological states.

The oxidation of indolepropionic and indolebutyric acids by peroxidase systems (R. H. Kenten)

A knowledge of the systems which are responsible for the metabolism of substances with growth-hormone properties may throw light on their mechanism of action in the plant. Work on the oxidation of indoleacetic acid (IAA) by plant extracts and peroxidase systems has already been reported. Two homologues of IAA, namely indolepropionic acid (IPA) and indolebutyric acid (IBA), are also oxidized by peroxidase systems. Both IPA and IBA have growth-hormone properties, and a study of their oxidation has been made, partly on account of interest in systems which may be responsible for their metabolism, and partly because the results might help to elucidate the mechanism of oxidation of IAA.

In contrast to the results obtained with the peroxidase-catalysed oxidation of IAA by O_2, where the presence of monophenols, maleic

hydrazide or Mn^{2+} increased the rate of oxidation, it was found that peroxidase catalysed the direct oxidation of IPA or IBA only when Mn^{2+} was present. The oxidation of IPA or IBA by peroxidase plus Mn^{2+} was usually preceded by a lag period which could be overcome by the addition of small amounts of H_2O_2. The addition of catalase stopped the reaction, suggesting that it was accompanied by, and depended on, the formation of H_2O_2.

The oxidation of IPA takes place without the formation of CO_2, and proceeds at concentrations of peroxidase and Mn^{2+} commonly encountered in plant extracts. These facts, together with other evidence, suggest that the oxidation of IPA by plant extracts observed by other workers was due to the presence of peroxidase and Mn^{2+} in the extracts.

Although the oxidation products of IAA, IPA and IBA were not characterized, from the results obtained in these and other investigations it is likely that the indole nucleus is the site of peroxidase attack.

Studies on some Leaf Components

The susceptibility of French beans to infections with tobacco necrosis virus (G. H. Wiltshire)

The studies of the change in concentration of organic acids in leaves, included in the Reports for 1953 and 1954, were extended and completed. In addition to citric, malic and ascorbic acid, French bean leaves contain *iso*citric, glycolic, malonic, fumaric, succinic and one as yet unidentified acid. The content of each of these acids can be altered by darkening the whole plant or leaves detached from it, by infiltration with the potassium salts of these and other acids or by placing the plant in an atmosphere containing little carbon dioxide. Changes in composition have been compared with changes in susceptibility to infection. The largest changes in acid composition were produced by darkening (increase in citric and decrease of malic and other acids), whereas the largest alteration in susceptibility (a decrease) was produced by detaching the leaf. There was no correlation between concentration of any one acid and susceptibility to tobacco necrosis virus, and none of the acids infiltrated into detached leaves altered susceptibility as much as did changes in the environment. It was confirmed that plants darkened or placed in an atmosphere containing little carbon dioxide for 2 days before inoculation are sometimes more susceptible than control plants, but at other times they are not. Some progress was made towards defining conditions under which the response is reproducible.

Properties of fractions from leaves infected with tobacco mosaic virus (N. W. Pirie)

From tobacco plants infected with tobacco mosaic virus many preparations have now been made of a non-infective antigen related to the virus but with a much smaller particle size. This resembles the virus in many ways; thus it contains firmly bound ribonucleic acid, it is not digested by the common proteolytic enzymes and it aggregates readily *in vitro* to give rods very similar to those of the virus. It contains only a third to a tenth as much nucleic acid as the virus, and much effort has gone into verifying that some nucleic

acid is invariably present regardless of the strain of virus used or the conditions under which the host plants are grown. During the past few years we have found much less slowly sedimentable material in extracts from infected leaves than we found ten years ago, and have no explanation of this. We confirm our old observation that the fraction of virus that is only liberated from the leaf fibre by fine grinding is less infective than the fraction that comes away more easily, but in other respects the two fractions are similar. (With F. C. Bawden.)

Work on the non-infective antigen produced an abundant supply of fresh centrifugally isolated virus, and the opportunity was therefore taken to co-ordinate the scattered observations made during the last ten years. All preparations, made from fresh sap, that have not been incubated contain labile nitrogen and phosphorus. This is mainly split off by incubation with citrate or phosphate, especially in the presence of trypsin or nuclease, but its removal is accompanied by changes in the virus, particularly in its behaviour on precipitation with antiserum or ammonium acetate. This behaviour is probably due to the presence of normal leaf nucleoprotein in virus preparations made by gentle methods. These preparations also contain ribonuclease, and the experience gained with this enzyme (described in earlier Annual Reports) has been of great value in controlling its assay and removal.

Large-scale production of leaf protein (M. Byers, D. Fairclough and N. W. Pirie)

The dry summer did not seriously affect work on protein extraction. Even during the drought period, when the dry-matter content of some of the harvested crops rose to 36 per cent, protein precipitates contained 60 per cent protein with an extraction of 30–40 per cent of the original crop nitrogen. This was obtained by adding water or dilute alkali to the leaves during pulping and adjusting the degree of pulping by varying the speed and pitch of the pulper hammers. The results have emphasized the findings of earlier work in that the degree of pulping, controlled by means of variable speed and pitch of the pulper hammers, affects the quantity and quality of the extracted protein from suitable raw materials. A typical example is given in the table on page 86.

Here samples of the same batch of kale were pulped at four different speeds, and at each speed the same two settings of the hammers were used. The coarse setting gives rapid movement through the pulper, and the fine setting slower movement, so that pulping is more complete. Obviously this increases the extraction without necessarily increasing the power consumption. Other experiments have shown that the precise distribution of the two types of hammer in the pulper affects the power consumption when other factors are kept the same. The ultimate economics of the process depend on our being able to find a set of optimum speeds and settings for each type of crop.

The new conveyor press installed in 1954 works well, both for protein extraction and for dewatering steamed crops. The water ratio of grass and other crops can be reduced from 6 : 1 to 2 : 1 quite easily after steaming, for the expenditure of 1 h.p. on the press motor, at a throughput of 10 cwt./hour.

A continuous process of protein precipitation has been developed to replace the batch method used hitherto. Live steam is injected along the bottom of a vertical U-tube through which juice flows. The steam mixes with the cold juices, giving an almost instantaneous rise in juice temperature. A thermostat bulb near the discharge point of the hot juice at the top of the " up " leg controls a flow valve for the cold juices entering the " down " leg of the U, and so keeps the temperature of the discharge at 80° C. This steaming unit simplifies the whole operation, and the coagulum filters much more easily than that produced by slower batch heating.

The effect of varying the speed and pitch of the pulper hammers

Pulper speed r.p.m.	Hammer settings	Through-put per hour, cwt./hr.	Power required per ton pulp kw.hr./ton	Extraction of N in Juices. 1st Extract. Total N as a percentage of crop N	Protein N liberated from fibre expressed as g. N from 1 ton pulp (4·675 kg.N) gms.	Protein N liberated per kw.hr. used on pulper gms.
523	Coarse	17·5	4·6	4·12	128	27·8
	Fine	17·5	7·0	4·69	138·5	19·8
653	Coarse	20	8·0	10·2	325	40
	Fine	17·5	5·8	16·6	541	93
760	Coarse	21·8	9·4	17·8	595	63
	Fine	15·6	7·8	24·3	829	106
950	Coarse	14·5	14·8	19·2	511	34·5
	Fine	12·0	16·0	21·5	565	35·4

Raw material used—Kale. 15·4 per cent D.M.
5 October 1955. 2·91 per cent N on D.M.

After steaming, the juices are poured into vertical calico or nylon tubes 5 feet long and 5 inches in diameter. Quick-fitting clamps seal one end, and snap holders secure the other end to a filter funnel. 15–20 gal. are handled in a few minutes. More juice is pressed out of the protein paste by twisting the tubes in an automatic unit that keeps the torque on them constant as the juice comes away. Finally, the tubes are put under a beam press which gets the water content down to 50 per cent. In order to purify the protein still further, the coagulum cake is shredded, washed in water and filtered once more.

A wide variety of raw materials have been used to produce protein from a range of crops on the one hand, and to study the performance of the machinery on materials of different texture and composition. These crops include grass from leys and permanent pasture, lucerne, cereals, beans, kale, mustard, potato tops, sugar-beet tops, artichoke tops, nettles, " fat hen ", etc. The final product, after partial removal of the fat, is pale green or fawn in colour, tasteless and contains 10–13 per cent N (60–80 per cent protein).

The protein is got into a state in which it can be stored without disinfectants by extracting the water and part of the lipid from it

with methanol or acetone. We are not yet satisfied with our arrangements for extracting the lipids and recovering the solvents, but progress is being made. Different batches vary somewhat in their digestibility by enzymes *in vitro*. This is being investigated thoroughly because it may give a partial explanation of the low feeding value of some samples of leaf protein made in other laboratories.

Zinc distribution in leaves (W. S. Pierpoint)

Work on the decomposition of normal leaf nucleoprotein by leaf or pancreatic ribonuclease had suggested that some component of the nucleoprotein was inhibiting the action of the leaf enzyme more than that of the pancreatic one. This substance appeared to be zinc, and consequently a number of estimations have been performed to see if the nucleoprotein, or any other of the fractions of tobacco leaves obtained during its preparation, is particularly rich in this metal. There did not appear to be a concentration in any of the fractions. This may represent the even distribution of the metal in these fractions *in vivo*, or the disruption of some zinc-containing organelles during the fractionation procedure. It was noticed, incidentally, that old yellow tobacco leaves have a much higher zinc content than younger green ones when expressed on a dry-weight basis, but very little more on a wet-weight basis. This probably means that tobacco leaves accumulate zinc during their growth, but do not lose it as rapidly as other materials during their decay. In this respect they behave in a similar manner to certain cereals (Wood and Sibly (1949), *Aust. J. Sci. Res.*, **3**, 14).

Soil

The properties of resistant parts of fungal mycelium which might accumulate in soils (M. V. Tracey)

The mature puff-ball mycelium has so far resisted all attempts to induce its breakdown with enzymes. It was reported last year that a number of bacteria were being isolated (in collaboration with F. A. Skinner of the Soil Microbiology Department) from a suspension of mature puff-ball mycelium in water that, after standing some months, appeared to be undergoing fermentation. Two species of clostridia were isolated, one of which produced gas within a few days in anaerobic culture, with the mycelium as sole carbon and nitrogen source. At the same time the mycelium lost some of its dark-brown colour. But neither species, alone or in the presence of any of three aerobes isolated from the material, was able to effect any measurable chemical change in the mycelium.

Further work on the chemical fractionation of the mature puff-ball mycelium shows that dichloroacetic acid may be of promise as a solvent. It " dissolves " chitin, but it is possible to dialyse it away from extracts using cellulose membranes. Dispersed materials of high molecular weight can be recovered from the solution, and the dichloroacetic acid in the dialysate may be removed by ether extraction. Some degradation of chitin to soluble non-dialysable forms appears to occur under the conditions so far used, and the conditions of use of dichloroacetic acid need further definition.

A number of papers have been prepared that relate to topics

discussed in earlier reports, and these are now either published or in the press. The editing of *Modern Methods of Plant Analysis* has been completed, and the last volume should appear early in 1956.

The potato-root eelworm hatching factor (G. H. Wiltshire)

Some preliminary experiments have been done, in collaboration with the Nematology Department, on the isolation of the hatching factor from potato-root diffusate. They confirm that the factor is probably an acid which can be adsorbed on charcoal or on anion-exchange resins.

PLANT PATHOLOGY DEPARTMENT

F. C. Bawden

The mycologists moved to the new building during the year, and some of the old laboratories were modified to make them more suitable for work on viruses. T. W. Tinsley returned from his period of secondment to the West African Cocoa Research Institute. D. H. Lapwood was appointed to replace F. T. Last, who transferred to the Department of Insecticides and Fungicides.

B. D. Harrison and J. M. Hirst gained the Ph.D. degree, and G. D. Heathcote the M.Sc. degree, of London University. F. C. Bawden was awarded the Research Medal of the Royal Agricultural Society of England.

L. Broadbent was awarded a Kellog Fellowship and spent three months visiting universities and research stations in the United States and Canada. F. C. Bawden visited West Africa in February to advise the Government of the Western Region of Nigeria on the control measures against, and research into, swollen-shoot disease of cocoa. In December he attended a meeting of a study group in Paris called " to consider how U.N.E.S.C.O. might help to promote knowledge on cell growth with a view to assisting research on cancer." R. Hull attended the Congress of the International Institute of Sugar Beet Research held in Western Germany.

Viruses and Virus Diseases

Strains of tobacco mosaic virus

A virus that causes a mosaic disease of legumes in Nigeria was found to be serologically related to tobacco mosaic virus: so, too, was southern sann-hemp mosaic virus from India. Although many previously described strains cause necrotic local lesions in some varieties of French bean (*Phaseolus vulgaris*), none has infected leguminous plants systemically. The viruses from Nigeria and India are not identical, but both undergo similar changes when they are transferred from leguminous to tobacco plants. When obtained from systemically infected tobacco plants, both are very similar to our type strain of tobacco mosaic virus, but when obtained from systemically infected French beans they differ strikingly from it. Not only do they cause different symptoms in many plants, but they are only remotely related serologically to the type strain, have different electrophoretic mobility and different resistance to inactivation by ultra-violet radiation. One passage through bean or tobacco is enough to produce these changes, and inoculum derived from single local lesions undergoes the same changes as the original bulk inoculum. When virus from bean is inoculated to tobacco plants kept in usual glasshouse conditions with a mean temperature of 20° C., the inoculated leaves develop necrotic local lesions; for about 5 days after infection only the bean form of the virus is recovered from such leaves, but later the tobacco form begins to

appear in many. When inoculated plants are kept at 37° C., they produce no symptoms; the bean form of the virus reaches much higher quantities than at 20°, and the tobacco form is not produced. Thus, the change from one form to another depends not only on the species of plant infected but also on the environment in which the plant is growing. Whether the change from one form to another represents a reversible mutation or a phenotypic variation is uncertain. The changes in serological and physical properties induced by passage through different hosts may all arise from changes in the protein moiety of the virus while the nucleic acid remains constant.

Plants infected with all strains of tobacco mosaic contain protein that is serologically related to the virus but is not infective. Bean plants infected with the strains from Nigeria or India seem to contain unusually large quantities of such non-infective protein, for purified preparations of the specific protein from beans are, weight for weight, less than one-hundredth as infective as comparable preparations from tobacco when tested in *Nicotiana glutinosa*. (Bawden.)

The specific protein in plants infected with other strains of tobacco mosaic virus was fractionated and the part that is not sedimented at 40,000 r.p.m. found to contain from 0·1 to 0·2 per cent phosphorus instead of the 0·5 per cent present in infective virus preparations. This phosphorus, like that in preparations of the larger particles, seemed to be present as a nucleic acid. (Bawden and Pirie.)

All the components specific to infected plants have previously been thought to be serologically related to one another. Studying the serological behaviour by the gel-diffusion test, both in plates and in test-tubes with a blank layer of agar intervening between layers containing antiserum and virus preparations, suggests that this assumption is unjustified. Preparations are serologically heterogeneous, and serologically distinct components, all specific to infected plants, have been detected. The protein that usually accompanies tobacco mosaic virus when it is precipitated from sap by acid or salts, or when it is sedimented by high-speed centrifugation, seems not to be one of these antigens; after this contaminant is removed by incubation with citrate or trypsin, virus preparations still give more than one line of precipitation when tested against antisera by the gel-diffusion method.

A crystallized preparation of tomato bushy stunt virus also contained two serologically unrelated antigens that were not detected in healthy plants, but only one of these was sedimented by high-speed centrifugation. (Kleczkowski.)

The relation between carnation latent virus, potato virus S and potato paracrinkle virus

Last year we reported that carnation latent virus was serologically related to potato virus S, which occurs in stocks of many potato viruses without causing any symptoms. The strains of virus S in the varieties Arran Victory and King Edward have been studied in some detail and found to differ in several respects. Although serologically related, the two can be readily distinguished by precipitation tests with their heterologous and homologous antisera, and the one from King Edward infects tomato plants, whereas

the one in Arran Victory does not. It has long been known that all stocks of King Edward contain paracrinkle virus, and our results are compatible with the idea that the aberrant strain of virus S universally present in King Edward plants is paracrinkle virus. Many experiments were made to gain evidence that King Edward plants contain two viruses, without success. Sap from King Edward plants was treated in various ways, such as heated to different temperatures and diluted to different extents, and inoculated to tomato plants, which were then tested after three weeks for virus S and paracrinkle virus. All plants whose sap precipitated specifically with antiserum to virus S also caused paracrinkle when scions from them were grafted on to Arran Victory potato plants, and no plant behaved in only one of these two ways.

Plants already infected with one strain of a virus usually resist invasion by a second. The fact that Arran Victory plants, which contain virus S, develop severe symptoms when grafted with scions from King Edward plants seems, therefore, to conflict with the idea that paracrinkle virus is a strain of virus S. However, there are examples in other viruses of strains that are only remotely related serologically failing to protect plants against each other, and this may be another. Evidence in favour of this idea was provided by experiments which showed that virus S from Arran Victory and the serologically related virus from King Edward multiplied in originally virus-free plants of the potato variety Profijt without seeming to interfere with one another.

Paracrinkle virus has been much cited in discussions on the origins of viruses and used as an example of a virus that has arisen endogenously as a component of a higher plant. Our results make the idea that it arose in King Edward quite unnecessary. They suggest that it is simply a specialized strain of a widely occurring virus, other strains of which are aphid-transmitted. None of the strains now found infecting potatoes seems to be aphid-transmitted, but they may have derived from ones that were, such as carnation latent virus now is, and lost this property, together with the ability to infect such plants as carnation, during their protracted existence in plants propagated by tubers. Evidence that another virus can gain and lose the ability to be transmitted by aphids is given below.

We have now produced plants of the King Edward potato variety that seem to be free from paracrinkle virus and from anything that precipitates specifically with antiserum to potato virus S. These seemingly virus-free lines were produced by excising the apical meristems from the shoots of potato tubers, and growing them on nutrient agar. After they had developed enough, they were first grafted to tomato plants to produce sizeable shoots, when these were struck as cuttings. Repeated tests with various antisera and by grafting to Arran Victory potato plants failed to reveal the presence of any virus. (Kassanis.)

Potato virus C and Y

Ten years ago we reported that potato virus C was serologically related to potato virus Y and suggested that the two were related strains, despite the different diseases they cause and the fact that virus C could not be transmitted by aphids. The stock of virus C we then used has since been maintained continuously by inoculation

in series to *Nicotiana* sp. in the glasshouses. This year we have transmitted this virus by *Myzus persicae*, using the same techniques that failed previously. That the change in transmissibility represents a change in the virus during its existence in *Nicotiana* sp. is strongly suggested by the fact that new cultures of virus C in tobacco, obtained like the original one from potato plants of the variety Edgecote Purple kindly supplied by the Scottish Society for Plant Breeding, were not transmitted by *M. persicae*. No other change has been noted in the behaviour of virus C, and both the new and old cultures produce only necrotic local lesions when inoculated to Majestic potato plants. Transmission of the aphid-transmitted culture to Majestic and back to tobacco usually resulted in the loss of the ability to be transmitted by *M. persicae*, but a few tobacco plants infected from Majestic still contained aphid-transmitted virus.

The different abilities of virus Y and individual isolates of virus C to be transmitted by aphids seem not to be correlated with any difference in their distributions in the tissues of infected leaves. When leaves infected with any were exposed to ultra-violet radiation, the proportional drop in infectivity of the expressed sap was the same, suggesting that they were all at a higher concentration in the epidermis than in deeper tissues. The ability of *M. persicae*, when fasted and then allowed to feed for 2 minutes on infected leaves, to transmit potato virus Y from tobacco, declined in the ratio of 85 : 60 : 10 when the infected leaves were irradiated for 0, 40 and 80 seconds : the corresponding decrease in infectivity of expressed sap was about 10 : 5 : 2. (Watson.)

Barley yellow dwarf

Although virus diseases of cereals have received little attention in Britain, they may be prevalent and causing unsuspected losses. Certainly many plants in crops at Rothamsted and elsewhere show leaf symptoms in the spring suggesting that they are infected with barley yellow dwarf virus. From such plants on the Rothamsted farm, a virus was obtained that was transmitted by three species of aphids, of which *Rhopalosiphum padi* transmitted the most readily. The transmissions were made by first feeding aphids for 3 days on infected plants and then for 3 days on healthy ones. Tests were complicated by the fact that virus-free aphids cause yellow, partly necrotic lesions, but these appear only at the feeding sites, whereas symptoms of yellow dwarf occur later on the young leaves. Infected oats become characteristically red, which makes it a better experimental host than wheat or barley. In a field experiment with small plots of Plumage Archer barley, plants infected on 25 April yielded only 66 per cent as much grain as uninfected ones, and plants infected on 3 May yielded 84 per cent. After the initial reaction to infection the plants tillered well, and at harvest had the same weight of straw as uninfected ones, despite their lower grain yields. (Watson and Mulligan.)

Viruses of leguminous crops

Work was started on virus diseases of leguminous crops, and these also seem more prevalent than previously thought. Most lucerne plants taken from the Rothamsted farm were infected with a virus whose host range agrees with American descriptions for lucerne

(alfalfa) mosaic virus. Its properties *in vitro* also suggest that it is a strain of this virus, and electron microscopy showed it to have spherical particles of approximately 14 mμ diameter. What appears to be a strain of yellow bean mosaic virus was isolated from nursery stocks of Gladiolus, and a similar virus is very prevalent in red clover. A severe disease found affecting a crop of French beans seems to be caused by a virus not previously recorded. (Tinsley.)

Electron microscopy

The electron microscope continued to be used for routine observations of virus preparations, but many weeks' work was lost when the microscope was refitted and housed in new quarters.

After a visit to the Research Laboratories of Associated Electrical Industries Ltd., at Aldermaston, techniques for preparing specimens were changed. The evaporating plant was modified to make it suitable for carbon evaporation, and most specimens are now mounted on carbon films. After comparative tests, platinum replaced palladium as the shadowing metal. Although difficult to evaporate, it gives far superior results, as might be expected from its higher melting point and atomic weight. In collaboration with Mr. D. E. Bradley of A.E.I., attempts were made to demonstrate structure on the surface of tobacco mosaic virus rods, using an experimental high-resolution microscope at Aldermaston. It is clear that for success in work of this kind we must use either stained or shadowed virus mounted on carbon films, and not carbon replicas, which are too thick and give too little contrast.

The new microtome has reduced section cutting to a routine little more difficult than that involved in ordinary light microscopy. Considerable trouble has been experienced from the tissue disintegrating when the embedding methacrylate polymerises, apparently because the volume changes during polymerisation. It is most troublesome with large cells having rigid cell walls, and no doubt happened previously, but with the old microtome was not distinguishable from trouble in the cutting. Possible interaction between this trouble and reagents used for fixation are being studied.

Experiments were made to see if tobacco mosaic virus in tissue could be impregnated with solutions containing heavy atoms, so that its density might be raised enough to observe virus particles easily in sections still containing the embedding plastic. Both silver nitrate and phosphotungstic acid, at pH 2, stain purified virus, but exposure to pH 2 destroyed leaf tissue, even when it was already fixed.

From our and American work, it seems that the low internal hydration of the virus makes it unlikely to be stained to high densities without using treatments that do serious damage. Tomato bushy stunt virus particles offer more promise because they are considerably hydrated and have more space into which heavy atoms might be introduced.

Sections of a tobacco hair cell containing tobacco mosaic virus particles permitted a direct estimate of the number of virus particles in the cell. A typical hair cell, with a volume of about $2{\cdot}5 \times 10^5\ \mu^3$, was shown to contain about 6×10^7 virus particles, or 240 per μ^3. This compares with a figure of 50 particles per μ^3 calculated from infectivity tests on expressed sap.

When the microscope was out of action, much time was devoted

to a statistical study of the results of a series of test particle counts. This showed that contaminations were occurring in the Cascade Impactor, which collects the sprayed droplets on filmed grids. Contaminating drops are deposited in stage 3 of the impactor, and probably arise as " satellite " droplets formed on the impact of very much bigger droplets in stage 1. They are thus contaminated with material derived from a surface within the impactor, and the nature of this contamination depends upon what has recently been put through it. Once recognized, the difficulty is readily overcome by coating the inside surfaces of the impactor with a strong solution of calcium chloride; all droplets which have been in contact with the walls of the apparatus are then contaminated with crystals of calcium chloride and so recognized and omitted when counting. Nevertheless, the precision of counts is still less than that predicted theoretically. Our method will work at virus concentrations down to about 0·1 mg./l. for purified tobacco mosaic virus, and could be pushed further if the magnification of our electron microscope could be rapidly varied over a wide range, so that larger droplets might be used for dilute solutions. The method is now being used to study the way virus increases in recently infected leaves. (Nixon and Fisher.)

The control of potato virus diseases

Experiments were continued to test the effects of spraying potato crops with insecticides on the spread of leaf roll and rugose mosaic, caused by virus Y. At Rothamsted DDT emulsion was used on 0, 2, 4, 6 and 8 occasions. Aphids were few in spring, but multiplied rapidly during July, and the spray this year did not check infestations as thoroughly as previously, perhaps because the summer was unusually hot. A count during the second week of August showed 6,000 aphids per 150 leaves on unsprayed plots, compared with 2,500 on plots sprayed on 13 June and 14 July, 1,200 on plots sprayed on 13 June and 5 and 27 July, and 550 on plots sprayed on 13 and 23 June and 5, 14 and 27 July. The yields of tubers were unusually small and were unaffected by spraying.

Twenty-three other trials were made in different parts of Britain to find out for how long potato stocks can be maintained healthy enough to use as seed, when the crops are sprayed and diseased plants are removed.

To gain further information about the best time to apply sprays, plots containing 16 potato plants (12 healthy, 2 with leaf roll and 2 with rugose mosaic) were kept caged except for a single period of 3–4 weeks, and different plots were exposed at different times. The plots were sprayed with an insecticide at the end of their periods of exposure.

An attempt was made at Efford Horticultural Station to see whether the incidence of leaf roll and rugose mosaic in crops could be assessed by lifting tubers in mid-August, breaking their dormancy and immediately planting them again. It failed, for frost killed the haulms of plants growing in the open before symptoms appeared, and although rugose mosaic was usually identifiable in plants grown under glass, leaf roll was not.

Observations on plants grown from tubers saved from experiments made in 1954 showed that all four insecticides (" Systox,"

parathion, endrin and DDT emulsion) used at Rothamsted stopped leaf roll from spreading, but they only decreased the proportion of plants that contracted rugose mosaic by about one-quarter.

At Clavering, in Essex, where "Hanane" or "Systox" were either sprayed on the foliage or dribbled on to the ridges 3 times, or parathion was sprayed on the foliage 6 times, leaf roll did not spread, whereas its incidence increased 5 times (to 26 per cent) in untreated plots. Rugose mosaic increased in all plots, by 7 times to 35 per cent in unsprayed plots and by 6 times to 28 per cent in sprayed ones, and the trial with this stock has therefore been stopped after continuing for 4 years.

At Harlow, Essex, in the third year of a trial, unsprayed plots had 27 per cent of their plants with leaf roll, plots sprayed with DDT or endrin 5·5 per cent, and plots sprayed and rogued 1·5 per cent. Leaf roll increased 7 times in plots not sprayed in 1954 and by less than one-third in sprayed plots. In all plots the incidence of rugose mosaic was less than 0·5 per cent.

A similar trial at Efford, Hampshire, gave less satisfactory control of leaf roll, perhaps because the spraying was not thorough enough. Leaf roll incidence increased from 1 to 2·5 per cent in sprayed plots and to 5·3 per cent in unsprayed ones.

Another stock at Efford and two in possible seed-growing parts of Gloucestershire, which were sprayed in 1954, as a preliminary to starting combined roguing and spraying tests in 1955, all had less than 0·5 per cent of their plants affected with leaf roll or rugose mosaic.

The samples from the trial at Sutton Bonington, where tubers were planted at various dates and part harvested 12 weeks later and part after the haulm had died, showed that viruses spread much less in 1954 than in 1953. The table shows the percentages of plants with leaf roll and rugose mosaic obtained from tubers obtained from the various plots in 1954.

Time of Harvest	Planting date in 1954					
	12 Apr.	7 May	1 June	26 June	21 July	21 Aug.
Leaf Roll						
After 12 weeks ...	0	3·7	4·1	8·7	5·5	0·4
After haulm died ...	18·7	10·2	7·0	7·3	6·7	7·3
Rugose mosaic						
After 12 weeks ...	0·4	1·3	5·4	0·7	2·5	0
After haulm died ...	3·0	7·0	7·3	3·0	3·8	0

As before, virus diseases were least prevalent in plots planted very early or late and lifted 12 weeks later. Again, seed tubers harvested after the haulm died gave plants that yielded 10 per cent more tubers than did seed harvested after 12 weeks' growth. Seed from the last two plantings yielded less than that from the others. (Broadbent and Heathcote.)

Viruses of cruciferous crops

The value of sowing strips of barley and oats around cauliflower seed-beds to decrease the incidence of mosaic was again tested at Luddington Experimental Station. Although the cereals grew poorly and were damaged by birds, and aphids were more numerous than in previous trials, there were only 2 per cent infected plants in

protected beds 6 rows wide and 2·7 per cent in beds 12 rows wide, compared with 5 per cent in unprotected beds.

We again co-operated with the Plant Pathologists of the National Agricultural Advisory Service in their annual survey of the incidence of cauliflower mosaic, by operating 14 aphid traps in different parts of England. *M. persicae* were few until August, when they became numerous, especially in the Midlands, and they remained so during September. *B. brassicae* were very numerous during August in Bedfordshire and during September and October in Cheshire, Yorkshire and Northumberland.

Work was continued on the host range and properties of the turnip viruses. The Edinburgh and Northumberland strains of yellow mosaic virus were inactivated by heating sap for 10 minutes at temperatures between 75° and 80° C., and turnip crinkle virus between 80° and 85° C. Both viruses were transmitted from infected to healthy plants when the leaves were in contact in a wind-tunnel, through which air was flowing at 5 miles per hour.

Turnip crinkle virus has still been found only on one farm in Kincardineshire. Its host range extends beyond the *Cruciferae*; it causes necrotic local lesions in *Chenopodium amaranticolor* and *Gomphrena globosa*, and becomes systemic in *Datura stramonium*, *Reseda odorata* (Mignonette) and *Cleome spinosa*. (Broadbent and Heathcote.)

Dr. Ch. Martini, Institut für Pflanzenkrankheiten, Bonn, spent 7 months here, and studied the transmission of the turnip viruses by flea-beetles. Both viruses could be transmitted immediately by beetles that had fed for only a few minutes on infected leaves, contrary to other workers' results with turnip yellow mosaic virus. In similar conditions, beetles transmitted yellow mosaic virus more often than the crinkle virus. Beetles that fed for longer than a day on infected plants transmitted less often than those which fed for 12 or fewer hours.

Sugar-beet virus diseases

A virus obtained from wild beet, in which it seems to be common, causes discrete yellow or light-green rings in sugar beet; in old leaves the rings coalesce to give a pattern of green rings on a yellow background that is characteristic and from which the virus has provisionally been called "water mottle". It does not protect plants against infection with sugar-beet mosaic virus, but the two are transmitted by aphids in the same manner and in some conditions produce very similar symptoms. A difference is that the water-mottle virus makes the under surface of the main veins necrotic, so that the leaves bend backwards, and the necrotic lesion may spread to the petioles and eventually kill the leaves; it also gives more and better-defined local lesions in tobacco than does mosaic virus, and twice during the winter has become systemic in inoculated tobacco plants. Whether it is a distinct virus or an aberrant strain of beet mosaic virus is undetermined. (Watson.)

When transmitted to inbred lines of sugar beet, various isolates of beet yellows virus consistently produced symptoms of different severity. When titrated against virus antiserum, the sap from plants with the most severe symptoms also gave the highest precipitation end-point. Isolates that were most virulent towards

sugar beet either failed to infect *Capsella bursa-pastoris* or caused only a mild disease, whereas isolates least virulent towards sugar beet severely stunted it and turned its older leaves purple. Sap from infected *C. bursa-pastoris* did not precipitate specifically with antiserum to yellows virus. The diseases caused by the various isolates in *Chenopodium virgatum* and *Nicotiana clevelandii* in general paralleled in severity those caused in sugar beet, but isolates that caused vein etch and yellowing in beet sometimes produced only one or other of these symptoms in *N. clevelandii*. The precipitation end-points obtained when sap from diseased *N. clevelandii* was titrated against antiserum were highest from plants that showed the most severe symptoms.

Beet plants infected with any of eight isolates that cause various degrees of yellowing and etching were protected against subsequent infection by the most virulent isolates. Not only did the characteristic symptoms caused by the virulent strains alone fail to develop, but the plants infected with the less virulent strains and then colonized 14 days later with aphids carrying virulent ones gave roots the same weight as those infected only with the less virulent strains and heavier than those from plants infected only with the virulent strains. Plants infected simultaneously by aphids carrying strains of different virulence developed symptoms intermediate in severity between those caused by plants infected with either strain alone. Yield of roots was again correlated with severity of leaf symptoms; uninfected plants in pots yielded roots averaging 19·2 g., to be compared with 4·8 g. for those infected with the most virulent strain, 12·8 g. with the less virulent strain and 8·8 g. for plants infected with both strains. In field plants of commercial beet varieties, however, there was no sign of such interference between strains, and plants infected with a virulent and avirulent strain simultaneously yielded no better than plants infected only with the virulent one. In a replicated field trial with virus strains that produce diseases of different grades of severity in glasshouse plants, loss of yield in roots was correlated with severity of leaf symptoms shown under glass. (Blencowe and Hull.)

Small field tests with 272 progenies, obtained by self-pollinating plants selected because they produced large roots although they had yellows, showed large differences in leaf type and in reaction to infection, loss of yield from infection in seedlings ranging from 35 to 66 per cent. Most of the progenies yielded less than commercial varieties, but a few yielded more, both when uninfected or infected with yellows virus, and some did so only when infected.

Larger experiments were possible with inbred progenies selected in 1953, but unfortunately the plants suffered severely from drought. However, some of the lines yielded as much sugar per acre as a commercial variety when uninfected and yielded more, and looked greener, when infected with yellows virus.

A chlorosis that developed in some seedlings raised from the inbred line H2S seems to resemble the "41 yellows" found some years ago in breeding lines in Eire. Seed from one plant produced 8 per cent and from another 20 per cent of yellowed seedlings, and seed from one cluster sometimes produced both healthy and yellow seedlings. The cause, presumably a seed-transmitted virus, was transmitted from affected to healthy seedlings by aphids. Infection

with it did not protect plants against subsequent infection with yellows virus. The two inbred plants that gave this seed were infected with the yellows virus as seedlings and later selected in the field for propagation because they showed unusually brilliant yellowing. No seed from any other infected plants has given diseased seedlings. (Hull.)

Experiments to test how spraying with insecticides affects the incidence of yellows in the root crop were made at Cambridge, Bury St. Edmunds, Norwich and Boston. Although much of the summer seemed favourable for aphid flight and multiplication, only few *Myzus persicae* were found on the experiments, and large populations of *Aphis fabae* developed on only one.

The materials used did not kill all the aphids on the plants, possibly because of the hot weather when they were applied. A day after the third spraying at Cambridge there was a geometric mean of 90 *A. fabae* per plant on unsprayed plots, compared with 22 on those sprayed with "Systox", and 4 on those sprayed with "Metasystox". Plots sprayed with a commercial formulation of DDT in oil (a satisfactory aphicide for potato crops) had as many aphids as did the unsprayed plots. Three weeks after being sprayed with "Systox" or "Metasystox", plants had the same aphid population as unsprayed ones, and those sprayed with the DDT had higher populations.

At Bury St. Edmunds there was a geometric mean of 10 *A. fabae* per plant on the control plots in late July. Plots sprayed two weeks previously with "Systox" or "Metasystox" had 5, and plots sprayed with DDT had 70. The plots sprayed with the three materials on earlier occasions in June had the same number of aphids as the controls.

Spraying with "Systox" or "Metasystox" at the middle or end of June decreased the incidence of yellows to one-fifth, and spraying on both occasions was no more effective than spraying on either one. A spray in mid-July was effective only at Norwich. A mid-June spray of DDT emulsion decreased the incidence of yellows by two-thirds, but later sprays had no effect. At the end of August fewer than 15 per cent of the plants were infected; expected yield increase from spraying was under 4 per cent and was not detected by lifting samples from the plots.

The effects of two sprayings with "Metasystox" on yellows incidence were determined in 16 experiments arranged in co-operation with the sugar-factory agricultural staffs. Fewer than 5 per cent of plants had yellows at the end of August on the unsprayed plots of 8 experiments, and only 4 experiments had more than 10 per cent of plants with yellows. Spraying decreased the incidence of yellows; it prevented large aphid infestations from developing on most experiments and kept the plants reasonably free from aphids for 7 to 14 days.

At Dunholme, where plots were surrounded by plants artificially infested with viruliferous *Myzus persicae*, "Systox" and "Metasystox" decreased the incidence of yellows by one-third at the beginning of September, and by one-eighth in mid-October; endrin and DDT emulsion had no effect either alone or when applied with systemic insecticides.

An experiment to find the interactions between cultural factors

and spraying with a systemic insecticide was repeated. Two dates of sowing, two levels of fertilizer dressings and two levels of plant populations were compared. No cultural treatment produced large differences in the incidence of yellows; the largest response to spraying three times with "Systox" (about 1 ton/acre of beet) was from plots with full fertilizer and high plant population, the treatments that yielded best. (Blencowe, Firth, Gates and Hull.)

Beta vulgaris spp. *maritima* grows abundantly on the eastern coast of England from the estuary of the Thames to south of Lowestoft, near Blakeney in N. Norfolk, and around the Ouse estuary near King's Lynn. A survey was started to estimate its importance as a perennial host plant of yellows virus and other pests and diseases of the commercial sugar-beet root crop. Most plants examined were infected with either yellows or beet mosaic, or both, viruses. *Peronospora schachtii* was locally abundant on wild beet, and in some areas the plants were heavily infested with larvae of the mangold fly. In two places yellows and mosaic had spread from wild beet to adjacent fields of commercial beet, but whether wild beet is generally an important virus source for beet crops in the coastal districts is still unknown. The wild beet were not colonized by aphids in the summer.

On low-lying coasts, *B. maritima* is mainly confined to the region of the equinoctial high-tide-mark, but sea flooding in January 1953 extended its distribution. Apparently seed floated inland with the flood waters, and wild beet is now established as a weed of hedgerows and waste ground. Whether it will continue in this unaccustomed habitat remains to be seen. (Blencowe.)

"Conserbeta", a proprietary powder designed to check the sprouting of clamped mangolds and fodder beets and to kill aphids, halved the growth of shoots from roots whose leaves and main growing point had been removed, but inhibited growth from untopped mangolds by only 11 per cent. Topping alone reduced sprout length; shoots from the shoulder buds on topped roots averaged 1·3 inches when the apical shoots from untopped roots were 5·0 inches. (Cornford.)

The samples of commercial sugar-beet stecklings planted at Dunholme averaged 2·4 per cent of plants with yellows; those from eastern England that were sprayed during the autumn with insecticides had 3·4 per cent, those grown under cover crops had 1·4 per cent and those from the north of England 2·1 per cent infected plants. Many of the samples grew poorly, only one-quarter of the plants surviving in some plots. Some of the loss could be attributed to downy mildew (*Peronospora schachtii*), which was commonest on stecklings from open beds in East Anglia, and to the stecklings being very small, but many large stecklings that seemed healthy when planted also failed to grow, despite favourable weather soon after planting.

In the autumn of 1955, 127 sugar-beet steckling beds had on average 0·38 per cent of plants with yellows when inspected by National Agricultural Advisory Service and British Sugar Corporation officers. Discarding 5 beds with over 2 per cent of infected plants decreased the average to 0·21 per cent. Mangold and fodder-beet steckling beds had up to 8·7 per cent of infected plants and the average for 180 beds was 0·63 per cent. (Firth and Hull.)

Plots of stecklings at Dunholme sprayed 5 or 3 times in the autumn of 1954 gave seed crops containing 6 and 10 per cent infected plants when the spray was "Metasystox", 8 and 29 per cent when "Systox", 9 and 20 when parathion, 4 and 13 when endrin and 8 and 15 when DDT.

Seedlings can be made aphicidal when seed is soaked in solutions of Hanane or N.C.7 before it is sown, but the treatment decreases germination. Watering the rows at the time of drilling affects germination less and made seedlings aphicidal for 3 weeks. (Gates.)

Mycology

Potato blight

Experiments started in 1954 to find the importance of seed tubers infected with *Phytophthora infestans* in initiating outbreaks of potato blight were continued in 1955, when more than 400 naturally or artificially infected tubers were planted, either in an unheated glasshouse or in the open. Although 11 per cent of those raised under glass produced stem lesions, showing the spread of the fungus from the tubers, none planted in the open produced any. The need for a suitable environment before such lesions are produced was further emphasized by their occurrence, despite the dry weather, in July on potato plants found growing from discarded tubers in tall grass.

Where blight occurred in the unusually warm and dry summer, it did so late and spread only slowly until late in September, when crops that had not already matured became heavily attacked. In such conditions protective sprays were not expected to increase yield; they had no effect on the yield of Majestic at Rothamsted and decreased the yield of King Edward by about 1 ton/acre, which was not statistically significant.

For five years observations on the occurrence of weather fulfilling Beaumont's criteria for forecasting outbreaks of potato blight have been made in usual Stevenson's screens and in potato crops. In wet summers there is little advantage in making measurements in the crops, but in average or dry years forecasts based on such measurements are more reliable than those made 4 feet above ground. Unfortunately there seems little hope of improving the criteria to be applied in screens 4 feet above ground, because the differences between screen and crop measurements result chiefly from such factors as soil moisture and density of crop that vary with each crop.

Apple scab

Our work with the National Agricultural Advisory Service in the Wisbech area again demonstrated the importance of ascospores as the cause of early infections of apple scab (*Venturia inaequalis*). In the course of this work it has become obvious that the extensive use of organic mercury compounds as curative sprays has created a need for accurate methods of detecting the kind of weather that permits infection. Workers in the United States consider that infection occurs when leaf surfaces remain wet for longer than a minimum time, which varies with the temperature. In 1955 we confirmed that the dew balance could be used to measure the time that apple leaves were wet, and it seems that the design of a simpler

balance might allow weather favouring infection to be detected at many places and lead to greater accuracy in the timing of curative sprays.

In addition to the Wisbech area, where Bramley's Seedling is the predominant variety, a trap was operated at Sudbury, Suffolk, in an orchard of Worcester Pearmain and Laxton's Superb. Ascospores occurred three weeks earlier and were over six times as numerous at Wisbech as at Sudbury.

To estimate the number of ascospores produced in different localities by different varieties, and to test the efficacy of methods of preventing their liberation, two small wind tunnels were made to study spore liberation. These allow the total number of ascospores liberated from unit area of different samples of dead leaf to be compared. Preliminary trials with this apparatus in 1955 showed differences between the spore content of leaves from Wisbech and Sudbury orchards similar to those indicated by operating spore traps in the orchards; they also showed that, after spraying with DNOC, dead leaves liberated only 1 per cent of the ascospores liberated from unsprayed leaves. (Hirst and Stedman.)

Pea wilt and foot-rot

Serious outbreaks of pea wilt, caused by *Fusarium oxysporum* f. *pisi*, and of foot-rot, caused by *Fusarium solani* f. *pisi*, were seen in S.E. England; wilt was particularly prevalent in Essex. From N. Suffolk, a bacterium was consistently isolated from diseased peas occasionally together with *F. oxysporum*. When inoculated to the varieties Onward and Charles I in the glasshouse, either organism alone caused only a mild disease, whereas both together caused the lower leaves to wilt and collapse. The bacterium has not yet been identified.

A field experiment at Rothamsted, in which soil was artificially inoculated, showed that *F. solani* spread along pea rows more rapidly than did *F. oxysporum*, and that simultaneous inoculations with both fungi decreased the rate at which both spread. An experiment to test the effects of soil inoculum introduced with peas sown in March and late April on yields of fresh weights gave inconclusive results, although fewer seedlings emerged and the plants were shorter in the inoculated plots. These experiments are being repeated, together with similar ones on an infested field in Essex.

Further work on the variability in *F. oxysporum* f. *pisi* indicated that the formation of heterocaryons (hyphae containing nuclei from genetically different cells) may be a method whereby pathogenicity is altered. Heterocaryons formed between two mutant strains, produced from a virulent wild-type culture by exposure to ultraviolet radiation and each weakly pathogenic, were as pathogenic as the original wild type.

Cultures were derived from single spores formed by heterocaryons between physiologic races 1 and 2 of *F. oxysporum* f. *pisi* and 3 out of 10^8 of these combined properties from both races. These new combinations of properties were detected by studying the nutritional requirements of the cultures and their ability to tolerate growth products of an Actinomycete. Two cultures that combined properties from races 1 and 2 infected a variety of pea that is not attacked by either of these races and that previously has been found

susceptible only to race 3. It seems that *F. oxysporum* has a system resembling the "parasexual" cycle that has been described for some other Fungi Imperfecti, and this system, which allows different nuclei occasionally to exchange genetic material, may be one factor responsible for originating races able to infect previously resistant plants.

An attempt to gain information on the mechanism whereby different pea varieties resist infection by some races of *F. oxysporum* was made by studying the effects of root exudates from different varieties on the growth in culture of the three races. Sterile water was continuously circulated over the roots of plants growing under sterile conditions, and the final solution was concentrated *in vacuo* at 40° C. Exudates from roots of varieties that resist infection by a given physiologic race inhibited the germination of spores of this race. Exudates from young roots inhibited more strongly than exudates from old ones. Concentrated exudates contained in porcelain cylinders on agar media also inhibited the mycelial growth of races which the variety of pea resists but not the growth of those which infect it. Sections through inoculated pea roots showed that races incapable of wilting a variety were checked in the outer layers of the cortex and never reached the stele. This also was most obvious at the early stages of the plant's growth.

Extracts from lesions caused by *F. solani* in stem bases suppressed the germination of spores of *F. oxysporum*, whereas extracts from normal stem bases did not. This toxic effect on *F. oxysporum* of stems infected with *F. solani* may explain the phenomenon observed in earlier experiments, that infection with both fungi causes a less severe disease than the wilt caused by *F. oxysporum* alone. (Buxton.)

Effects of ultra-violet radiation on plant pathogens

As with other cells, the damaging effects of ultra-violet radiation on spores of plant pathogenic fungi can partly be offset by visible light. Irradiated suspensions of spores of *Botrytis fabae*, the cause of chocolate spot of broad bean, or of *Uromyces fabae*, the cause of broad bean rust, produced many more infections when the spores were exposed to light before being inoculated to plants, or when the inoculated plants were exposed to light, than when they were kept in the dark. Exposing the inoculated plants to light increased infections by *B. fabae* more than did exposing the irradiated spore suspensions. When spores were irradiated similarly at different times after suspensions were rubbed on leaves, the proportion that infected increased with increasing time between inoculation and irradiation; with a dose so that spores irradiated immediately after inoculation gave 3 per cent of the infections produced by unirradiated suspensions, those irradiated after 4 hours produced 13 per cent and those irradiated after 8 hours produced 93 per cent. These results suggest that germination increases resistance to inactivation by ultra-violet radiation and that, once the fungus has penetrated the epidermis, it is protected from the radiation.

Irradiating bean leaves increased their susceptibility to infection by *Botrytis fabae*, so that the same inoculum produced more lesions and larger ones. It had no effect on infection by *Uromyces fabae*. (Buxton and Last.)

When resting spores of *Plasmodiophora brassicae*, the cause of clubroot of crucifers, were exposed to various amounts of ultra-violet radiation and then inoculated to cabbage seedlings growing in water culture, two effects were observed: (1) loss of ability to produce zoosporangia in infected root hairs, and (2) loss of ability to infect root hairs. Doses of radiation too small to affect ability to infect root hairs left only 5 per cent of the spores able to develop to the stage of forming zoosporangia. Whether these effects can be reversed by visible light is being studied, but the study is complicated by the fact that visible light itself seems to inactivate resting spores. Exposure to direct sunlight for only short periods prevented spores from infecting, and results were inconsistent when less intense light was used. The component of sunlight that inactivates is unlikely to be in the ultra-violet region, because it passes through glass.

Spores irradiated to the extent that zoosporangia are not formed, though infections occur, are also less effective than normal spores in causing "clubs" to form. Such exposures to ultra-violet radiation decreased the weight of clubs to the same extent as did diluting the inoculum fifty-fold. Diluting to this extent decreases the number of root hairs that become infected to about the number that develop zoospores when infected with undiluted suspensions irradiated for the correct time. This suggests that infections which fail to form zoosporangia in root hairs do not develop further and confirms observations made on roots infected by irradiated spores.

Results of experiments showing that the antibiotic griseofulvin, either sprayed on the leaves of cabbages or applied to the soil in which the plants were growing, checked the development of club root are described in the report of the Insecticides and Fungicides Department. (Macfarlane.)

Cereal diseases

The weather greatly favoured the development of eyespot, *Cercosporella herpotrichoides*, in wheat sown in October, but crops sown late were checked by cold in January, and less severely infected. Take-all, *Ophiobolus graminis*, was more prevalent than usual at Rothamsted, both on autumn- and spring-sown wheat, growing where wheat or barley had been taken recently. Ergot, *Claviceps purpurea*, which very rarely occurred on wheat at Rothamsted 20 years ago, usually occurs now every year. The harvested grain from wheat on Long Hoos averaged 1 sclerotium in 400 g. Black stem rust, *Puccinia graminis*, was fairly severe on spring- but not on autumn-sown wheat.

Broadbalk was drilled unusually late and was less affected by eyespot than usual; the average incidence in 8 plots after crop was 48 per cent infected straws, 32 per cent severely; after fallow 18 per cent were infected, 8 per cent severely. Take-all was commoner than usual in sections following wheat. It was again negligible after fallow and most serious on the three plots that receive no nitrogenous fertilizer; it was less severe than in some nearby fields where wheat followed wheat, suggesting that some condition in Broadbalk is inimical to take-all. The incidence of eyespot or take-all varied from plot to plot in Section V, which was limed in 1954, but an average of all plots was the same in the lightly and heavily limed parts.

The wheat in the four- and six-course rotation experiments was sown in October, and the eyespot incidence was above average. In the four-course, 60 per cent straws were infected, 43 per cent severely, and in the six-course, 44 per cent straws were infected, 21 per cent severely.

The curious white-straw disease, caused by *Gibellina cerealis*, which is not known to occur anywhere else in Britain, was again recorded in wheat on the alternate wheat and fallow.

In the ley-arable experiment the percentage straws with eyespot lesions after arable, cut grass, grazed ley and lucerne were 43, 5, 1 and 7 respectively on Highfield, and 72, 7, 6 and 16 respectively on Fosters. About half of the infected plants had severe lesions, but the crops did not lodge, and yield was affected only on Fosters. Take-all was recorded for the first time in these experiments on 5 of the 8 plots after arable on Highfield, but on average only 4 per cent of the plants were affected. (Glynne, Salt and Slope.)

The effect on lodging in Proctor barley of sowing seed at 1, 2 and 3 bushels/acre was tested at different levels of nitrogen (0, 1½, 3 and 4½ cwt. sulphate of ammonia/acre). There was much less lodging than last year, but there was the same tendency for it to increase with increasing seed rate and nitrogen. Plots that received nitrogen averaged 3, 22 and 32 per cent of their areas lodged at harvest when sown respectively at 1, 2 and 3 bushels; plots receiving 0, 1, 2 and 3 doses of nitrogen had an average of 0, 2, 13 and 42 per cent of their areas lodged. Total grain yields, like last year's, averaged 42·9 cwt./acre for plots receiving nitrogen. Yield was not affected by seed rate; plots receiving one dose of nitrogen yielded 1·8 cwt./acre more than those with no nitrogen, 2 doses gave a slight decrease and 3 doses yielded 2·2 cwt./acre less than 1 dose. The amount of tail corn again increased with increase in seed rate and nitrogen, so that the yield of dressed grain was depressed by each additional bushel of seed; plots receiving nitrogen and sown at 3 bushels, yielded 4·8 cwt./acre less dressed grain than those sown at 1 bushel. Yield of dressed grain was again depressed by each dose of nitrogen, 3 doses yielding 7·0 cwt./acre less than 1 dose, 7·7 cwt./acre less than no nitrogen. (Glynne and Slope.)

In an experiment to measure the effects of previous crops on two varieties of wheat grown under good conditions, Cappelle sown on 15 October, after a crop of potatoes that received farmyard manure, gave 65½ cwt./acre on some plots, the highest yield yet recorded at Rothamsted. Plots receiving 3 and 6 cwt. " Nitro-Chalk ", applied half in March, half in May, averaged respectively 51½ and 60 cwt./acre. Holdfast, with the same treatments, gave 41½ and 44 cwt./acre. The large response to nitrogen of Cappelle suggests that its limit of yield may not yet have been reached. When following wheat instead of potatoes, but otherwise treated similarly, Cappelle gave a mean yield for all treatments of 20½, Holdfast of 14 cwt./acre; the proportion of tail corn was greater than where they followed potatoes. The very large differences in yield and quality of grain when wheat followed different crops was associated with a much higher incidence of eyespot, take-all and weeds in the crop following wheat. The weather was exceptionally favourable for eyespot and weeds in 1954 and 1955, and both were more prevalent than is usual at Rothamsted in the second successive wheat crop. Cappelle after

wheat had 76 per cent straws infected by eyespot, 50 per cent severely, Holdfast had 88 per cent straws infected, 74 per cent severely, supporting evidence from earlier pot experiments that Cappelle has some resistance to this disease. Take-all was more prevalent on the roots of Cappelle than of Holdfast. (Glynne and Slope.)

On light land at Woburn, winter wheat grown for a second year on the same land yielded only 14·6 cwt./acre of grain compared with 27·4 cwt. in the first year, the highest yielding plot of Cappelle giving only 28·8 cwt. compared with 50·2 cwt. in 1954. The lower yields in the second year resulted partly from a higher incidence of eyespot and take-all and partly from much increased weed infestation, *Agrostis gigantea* predominating.

Nitrogen gave large responses in both years; 6 cwt. of "Nitro-Chalk"/acre applied in March, April and May increased yield by 15·4, 22·4 and 13·9 cwt./acre respectively in 1954 and by 13·2, 13·8 and 3·3 cwt. respectively in 1955.

Eyespot affected Holdfast more than Cappelle. Its incidence was greatly increased by nitrogen, especially where applied in March; thus Holdfast given no nitrogen, and dressed in March, April and May had respectively 7, 42, 23 and 12 per cent straws infected at harvest in 1955. The crop on nitrogen-deficient plots was too sparse to favour infection by the eyespot fungus, but conditions became favourable when the luxuriance of the crop was increased by nitrogen.

Take-all was a little more prevalent than last year, 15 per cent of the straws having infected roots. There was more take-all on Cappelle (18 per cent) than on Holdfast (12 per cent), as at Rothamsted. "Nitro-Chalk" applied in April decreased the percentage infection more than where applied in March or May. (Salt.)

Potato skin spot

Attempts to produce skin spot on potato tubers with cultures of *Oospora pustulans* isolated from underground parts of growing potato plants failed, but the failure is not evidence that the isolates differ from those affecting tubers, for these also failed to cause skin spot under the conditions used.

Seedlings of both potato and tomato became infected when grown for a month in soil inoculated with an isolate from a tuber with skin spot, and such seedlings were used in preference to tubers for studying the persistence of the fungus in naturally and artificially infested soils. Soil in which potatoes had not grown for over 100 years gave no infections, but soil from an adjacent field, on which potatoes grew the previous year, gave 8 per cent infected seedlings in February and 2 per cent in March.

The underground parts of potato shoots of several varieties were examined in August at seven places where the National Institute of Agricultural Botany conducts trials of main crop potato varieties. The samples were classified in four categories according to the extent and severity of the attack by *O. pustulans* (Clean, 0; Slight, 1; Moderate, 2; Severe, 3) and the total score expressed as a percentage of the possible. The fungus was present at all places, but was commoner on some varieties and soil types than on others, although the same stocks of seed were planted at all centres. The seed tubers

used for the varieties Majestic, Orion and Dr. McIntosh had skin-spot lesions and, averaging all centres, plants of these varieties had disease ratings of 60, 56 and 48 per cent respectively, whereas Ulster Supreme, the seed tubers of which were free from skin spot, averaged only 10 per cent. The average rating of these varieties at different centres ranged from 23 per cent on black fen soil to 68 per cent on clay with flints. (Hirst and Salt.)

Sugar-beet diseases

At 11 out of 12 experimental sites, seed soaked in ethyl mercury phosphate and dusted with BHC gave an average of 10 per cent more seedlings than seed dressed with "Mergamma" (organo-mercury BHC seed dressing dust). In small-scale trials, "Captan" was almost as effective as ethyl mercury phosphate. Pouring solution or suspension of fungicide along rows drilled with seed dressed with ethyl mercury phosphate gave on average 6 per cent more seedlings.

In an experiment on the "Docking disorder", nitrate of soda almost halved the proportion of fangy roots, but the yield of roots was not increased above that given by other sources of nitrogen that scarcely affected fanginess. Drenching the rows with fungicide at time of drilling also halved the proportion of fangy roots. Magnesium nitrate prevented the yellowing of the interveinal areas of the leaves. (Gates.)

When conidia of *Peronospora schachtii* were placed at intervals of a few days on the leaves of sugar-beet seedlings, all plants of inbred line N4S5 remained healthy, whereas between 88 and 98 per cent seedlings of 5 other inbred lines were killed. (Cornford.)

NEMATOLOGY DEPARTMENT

D. W. Fenwick

B. G. Peters resigned from the headship of the Nematology Department at the end of September to take up a new chair of Parasitology at Imperial College, London. D. W. Fenwick served as acting head for the rest of the year. F. G. W. Jones was appointed to succeed B. G. Peters on 1 January 1956.

Mary T. Franklin spent four months from July to October in the United States and Canada. During the first three, spent at the Connecticut Agricultural Experiment Station, New Haven, help was given with problems connected with the tobacco cyst nematode, and with ectoparasites of the roots of fruit trees. The fourth month was spent in visiting nematologists in other parts of the States and in Canada. Short visits were made to thirteen laboratories where nematological research is carried out, and a great variety of problems was seen under investigation.

B. G. Peters, D. W. Fenwick, C. C. Doncaster and J. J. Hesling attended the International Symposium on Plant Nematodes at Wageningen from 29 June to 5 July: papers were read by C. C. Doncaster on the application of electron-flash microscopy to nematology and by J. J. Hesling on his work with *Heterodera major*.

B. G. Peters attended the Easter School on " Soil Zoology " at the University of Nottingham, lecturing on soil-inhabiting nematodes and demonstrating simple techniques for handling them. D. W. Fenwick gave a course of twelve lectures on nematology for the parasitology course at Imperial College, London, on a *locum tenens* basis. J. J. Hesling and C. C. Doncaster attended a course in microscopy at the Imperial College, London.

The following visitors worked in the department during the year: Mr. J. W. Meagher from the Plant Research Laboratories, Victoria, Australia (10 October onwards), Mr. G. Macdougal Mackintosh, Marischal College, Aberdeen (8–19 August), Mr. P. Holliday, from the Commonwealth Mycological Institute (19–24 September), Mr. J. W. Coles, from the Natural History Museum, London (19–24 September), Miss E. C. Mason and Miss A. Lyell from the National Agricultural Advisory Service Laboratories, Kirton (5–10 December). Mr. A. G. Whitehead is at present holding a Colonial Agricultural Studentship in the department.

J. B. Goodey and Mary T. Franklin have completed the revision of T. Goodey's *Nematode Parasites of Plants Catalogued under their Hosts* (1940). The revised publication is now in the hands of the printers.

The technical bulletin *Laboratory Methods for Work with Plant and Soil Nematodes* (T. Goodey, 1951) is being rewritten by J. B. Goodey, and much new material is being incorporated.

A stream of specimens have been received for identification, and many enquiries from all parts of the world have been answered. Time has been devoted to the teaching of basic concepts of nematology to the several visitors. This is necessitated by the fact that this is the only department of Nematology in the country.

Tylenchidae, Aphelenchidae and other Soil Nematodes

J. B. Goodey has continued investigations into the relationship between *Ditylenchus dipsaci*, at various levels of infestation, and susceptible and resistant varieties of oats. Other cereals have also been tested. The host ranges of several other biologic races of this eelworm have been further explored.

The relationship of mushroom to the attacks by various eelworms; *Ditylenchus destructor*, *Aphelenchoides* sp., *Panagrolaimus* sp. and *Hexatylus* sp. has received further attention. *Aphelenchoides* sp. proved to be a very active parasite. Pots of mushroom compost inoculated with 15 specimens soon stopped cropping. The mycelium was largely destroyed and the *Aphelenchoides* population had risen to about 3,000,000 within 6 weeks. A letter to *Nature*, jointly with members of the National Agricultural Advisory Service, has been written. The *Aphelenchoides* appears to be an undescribed species.

Single seedlings of Sitka spruce have been grown in glass tubes and inoculated with varying numbers of *Hoplolaimus uniformis* in an attempt to obtain direct evidence of the effects of this eelworm on Sitka. This work is part of the investigations being done by the Chemistry Department on nutritional problems in forest nurseries.

A paper, resulting from a critical study of specimens of some new species of *Iotonchium*, has been prepared and will appear in the first volume of a new periodical *Nematologica* (Leiden).

Mary T. Franklin, having established the specific characters of *Aphelenchoides parietinus*, has collected other species of doubtful standing in this genus in order to study them.

In conjunction with A. R. Forster she has carried out work on several species of *Meloidogyne* in the greenhouse and in the laboratory. This work has had two aims :

(1) In the heated greenhouse beds five known species and varieties of root-knot have been cultured. Additional information on their host ranges has been collected and fresh material obtained from which microscope slides have been made for morphological studies.

(2) A number of unidentified populations of root-knot nematodes has been studied in pot tests by means of prolonged host-range trials. The results of these have lent support to identifications based on microscopic observations of the nematodes concerned. In some cases it has become evident that more than one species is present. Several new populations have been received for identification and, when the material has been suitable, cultures have been started for host-range trials to help with the identification.

Nematodes Parasitic in Insects

H. E. Welch carried out studies on the parasitism by nematodes of the *Drosophila* (Diptera) population in the woods near Rothamsted Manor. Two new species of nematodes, both members of the Allantonematidae, were found to be parasitic in six of the twelve *Drosophila* species found in the woods. The taxonomy and life history of these worms has been worked out and observations made on their host–parasite relations. A collection and review of the

literature of the Mermithidae, an important group of insect nematodes, has been commenced and is now well advanced. In addition, a number of small investigations have been made of material sent to this department for identification.

Cyst-Forming Species of *Heterodera*

Heterodera rostochiensis

B. G. Peters has concluded his analysis of the results of the 1953 pot experiment on the pathogenicity of *H. rostochiensis* to potatoes. This experiment, in which potatoes were exposed to a geometric series of inoculum-densities of *Heterodera rostochiensis*, revealed, on further analysis, a number of relationships between original and final densities. Thus, with increasing inoculum the density of new cysts rose to a maximum and then declined, as also did the number of larvae hatching per cyst at the end of the experiment. However, the hatching curve expressed as a proportion of all larvae *rose* with increasing inoculum density.

Pot tests carried out with two halogenated-hydrocarbon fumigants have given interesting results in tests in glazed pots each holding 20 lb. of soil infested with *Heterodera rostochiensis*. Soil samples taken 4 weeks after injection showed that both fumigants have poor kills in comparison with " DD mixture " or allyl bromide. While one was phytotoxic, reducing plant height and yield of tubers significantly, the other stimulated yield. But the end-of-season soil samples showed that both fumigants had greatly reduced hatchable larvae per cyst and per g. of soil, the improvement over " DD mixture " and allyl bromide at this stage being highly significant.

Following B. G. Peters' departure, C. C. Doncaster and J. J. Hesling took soil samples and assisted with the final injections in the 6-year experiment at Wisbech, conducted in co-operation with the West Norfolk Farmer's Manure and Chemical Co-operative and Shell Chemicals Ltd. C. C. Doncaster has undertaken the processing of these and future samples. Next year's test crop of potatoes, along with soil samples, should show the effects (if any) of year/time of injection on populations of *Heterodera rostochiensis*.

D. W. Fenwick has now succeeded in obtaining sterile viable larvae of *Heterodera rostochiensis*. Treatment of larvae with commercial H_2O_2 for 8 hours rendered them sterile but destroyed their viability. Similar treatment of the eggs resulted in sterilization, and subsequent treatment of these with sterile potato-root diffusate resulted in the production of sterile larvae. Infestation experiments have shown that there is little, if any, loss of viability from this treatment. It is now hoped that it will be possible to infest tomato roots grown in sterile media with these larvae and also investigate the production of root diffusate under plant-tissue culture conditions.

Work on the respiration of *Heterodera rostochiensis* has commenced. Preliminary investigations indicated that the respiration rate of cysts was proportional to their egg content, the oxygen consumption being about 0·05 μl./hour per 1,000 contained eggs.

Liberation of the eggs from the cysts increased the oxygen consumption by a factor of $\times 4$, while the larvae themselves used about 8 times as much oxygen as did eggs within the cyst.

Experiments conducted in collaboration with E. Widdowson on the hatching of eggs of *Heterodera rostochiensis* have continued. Efficient sampling techniques have been evolved, and comparison of the hatching of larvae from eggs and from cysts has been made. In general, the same relationships have been found to be valid for hatching both from cysts and from eggs, but the latter was capable of greater precision for a given outlay of work and material.

The joint Agricultural Research Council project, with Professor R. H. Stoughton (Reading) and Professor Sir A. R. Todd (Cambridge), to investigate the chemistry of the hatching factor in potato-root diffusate has entered its last year; it is hoped that an analysis of the data from the assay tests will yield valuable information for the guidance of future workers.

E. Widdowson has continued her work on the production and storage of potato-root diffusate and has found the variety Arran Banner to be very suitable for this purpose. If grown in soil or in sand with or without nutrients in 6-inch pots, this variety proved capable of producing daily up to 200 ml. of diffusate of L.A. = 3·5 approximately for a period of up to 6 weeks. Storage of this at 3–4° C. resulted in an initial fall in activity of 0·4–0·5 L.A. units over the first 3 months; thereafter the activity remained constant for up to 1 year.

A. R. Forster has continued her investigations on the possible effects on resistance of a graft on its root-stock; plants of Tomato (host) and *Solanum nigrum* (non-host) were cross-grafted, grown in uninfested soil and inoculated with larvae of *Heterodera rostochiensis* after the grafts had become established. Cyst production on these plants was estimated. Side-shoots growing below the established grafts were removed, rooted in uninfested soil and *H. rostochiensis* larvae added. These plants were lifted at the end of the growing season and the cysts counted.

A similar experiment has been conducted using *Meloidogyne incognita*: plants of Tomato (host) and *Lycopersicon peruvianum* (non-host) were cross-grafted and inoculated with larvae of *M. incognita*. The plants were later lifted and the egg-masses and female nematodes counted. The analyses of these three experiments are not yet completed.

Heterodera cruciferae

C. C. Doncaster has completed a preliminary investigation into the life history and pathogenicity of *Heterodera cruciferae*. Cabbage seedlings grown in heavily infested soil for 2 days were transplanted to clean sand, 2 or 4 plants being removed daily for fixing and staining. The development of all stages of the parasite from invasion of the root by the second-stage larvae through the second, third and fourth ecdyses to sexual maturity was followed.

Sections of root containing adult worms showed considerable giant-cell formation. Heavily infested roots were badly stunted, the development of lateral roots having been arrested at an early stage; some swelling was apparent about the points of infestation. Leaves of heavily infested plants showed intervenal chlorotic marbling similar to that produced on plants grown in nutrient-deficient soil.

Observations have been made on the hatching responses of

Heterodera cruciferae in root diffusates from sprouts, swedes, rape and mustard. Leachings from all four species stimulated larval emergence to a comparable degree; mixing mustard diffusate with that from sprouts, swedes and rape had no apparent effect on larval emergence. A study of the hatching curve showed that it was a sigmoid. Dilution curves for mustard and sprouts diffusate were linear and parallel, and it was therefore considered reasonable to suppose that these diffusates could be assayed by the methods applicable to potato-root diffusate. An account of this work has been prepared and accepted for publication in the *Ann. appl. Biol.*

The use of low-power electronic-flash apparatus for photomicrography of nematodes has been investigated. The results obtained indicated that it could usefully be employed for recording many interesting occurrences observed under the microscope and for obtaining accurate records of the structure of living nematodes. A record of this work has been accepted for publication in the first volume of a new publication *Nematologica*.

Heterodera major

J. J. Hesling carried out a survey of the classical experimental fields of Broadbalk and Hoosfield for the presence of *Heterodera major*; on Broadbalk few cysts were present, and on many plots none were detected; on Hoosfield all plots appeared to be infested: on both fields few cysts had contents.

In the long-term experiment on build-up of *Heterodera major* at Stoke-on-Tern (carried out in conjunction with Mr. H. C. F. Newton) greatest increases occurred on the oat plots; the level of infestation remained constant in barley and decreased on rye. The experiment is just entering its third year, and further results are desirable to clarify the true nature of the population changes.

Population studies on cereal-root eelworm on commercial fields in Shropshire have shown that the eelworm populations have fallen during 3 years without host crops; when cereals were introduced into the rotation the fall in population was less marked. Similar observations on other fields indicated that eelworm populations were doubled with barley and halved with rape and black mustard.

A number of varieties of oats, barley and wheat have been tested for resistance to cereal-root eelworm without any marked resistance being detected in any.

Pot tests with oats, wheat and barley showed that slight damage occurred at such low levels of infestation that they might have been missed by routine soil sampling. Twenty-eight larvae per g. of soil caused severe damage to oats, wheat and barley, and was most marked in oats towards the end of the season. Population build-up is under investigation, both in this experiment and in another involving grasses.

Cysts of different species of *Heterodera* have been studied with a view to their identification, and a collection of slides has been prepared.

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

During the current year the following appointments have been made: Helen Salkeld to work on the effect of insecticides on pollinating insects, Janet Samuel to work on analytical methods for insecticides and R. Solly to work on biochemical effects of insecticides. Mr. Das from India has arrived in the department and started research for a higher degree. Mr. D. G. Glynne-Jones and Miss E. Hayton of the Kenya Pyrethrum Board, Mr. Clinch of Boots Pure Drug Co., Mr. J. P. P. Amaro from Portugal, Mr. D. Taylor from the Gold Coast, Mr. M. A. Nour from the Sudan, Mr. V. D. Krentos from Cyprus and Mr. Da Silva from Portugal have worked in the department during the current year.

The department has moved into fresh accommodation during the course of the year. The move has seriously interfered with laboratory work, although the field work was continued uninterrupted. The facilities in the new accommodation are not yet complete, and the work will be handicapped until they are. This is particularly true of the constant-environment facilities.

Physical Chemistry

Effect of temperature on relative contact toxicity of different sizes of particle

A. H. McIntosh and Margaret Macfarlane have finished their work on particle size and toxicity of contact insecticides. The following is a summary of the most recent work.

Some assumptions have been made about penetration of insect cuticle by solid contact poisons. The three most important assumptions are: (*a*) that a contact poison begins to penetrate insect cuticle by dissolving in the epicuticle wax layer; (*b*) that the poison must saturate the wax layer locally before any insects die; and (*c*) that if counts of kill are made before the "end point", the kill brought about by a fixed dose of one poison at one after-treatment temperature is decided by the length of time the wax has been saturated. In such tests of contact action, small particles of poison are more toxic than large ones, weight for weight; the after-treatment temperature of the insects may affect the absolute and the relative toxicities of the two sizes of particle. The assumptions lead to the conclusion that the effect of temperature on the relative toxicity depends on the temperature coefficient of internal action of the poison on the insect. This can be measured by injection tests. If the coefficient is negative or zero, the ratio of toxicities of the two sizes by contact action, measured at some time before the end point, will increase if the after-treatment temperature is lowered; but if the coefficient is positive, the effect of temperature on relative toxicity cannot be foretold.

These ideas have been tested by using aqueous suspensions of

DDT and two of its analogues ("Perthane" and "BNP" or "Prolan"), rotenone, 2-bromomercurithiophen, dieldrin and endrin. Suspensions of colloidal poison were used for "small particles", and suspensions of uniform crystals for "large particles". Their toxicities were measured on as many as possible of three species. The temperature coefficients of internal action were found by injection tests (*Tribolium castaneum* Herbst and *Tenebrio molitor* L.); tests of contact action were by the dipping method (*Oryzaephilus surinamensis* L. and *T. castaneum*), or the measured drop method (*T. molitor*). All counts of kill were made 24 hours after treatment. The results seem to confirm the assumptions.

This work is now being published.

Time, temperature and toxicity of insecticides

Mr. M. Das has started work on the effects of after-treatment temperature and time on the toxicity of insecticides. If a poison has, for example, a "positive temperature coefficient of kill", the kill is higher as the temperature after treatment is raised. This difference in kill will be permanent if the speed of action is unaffected by temperature. But if the speed of action is affected by temperature, any difference in kill may just be transient.

With DDT on *T. castaneum* at 28° C. and 10° C., the temperature coefficient of kill is negative; but it is the same 12 days after treatment as it is 1 day after treatment. The kills increase at the same rate at each temperature; each of the rates of increase in kill becomes less and less as time goes on, and about 12 days after treatment there are no further increases in kill at either temperature.

With "Valone" on *T. castaneum* at 28° C. and 10° C. the temperature coefficient is positive if counts of kill are made less than 20 hours after treatment. But if counts are made 20 hours after treatment the temperature coefficient is zero; and if counts are made more than 20 hours after treatment the temperature coefficient is negative. There are no further increases in kill after about 16 hours after treatment (28° C.) or 48 hours after treatment (10° C.).

This work is being continued.

Biochemistry

Isolation and properties of insect esterases

K. A. Lord and R. Solly have continued work on the separation of esterases from *Blattella germanica* L. adult males, and considerable progress has been made in the separation of esterase activities. The acetyl choline hydrolysing activity has been largely separated from enzymes which hydrolyse phenyl acetate but not acetyl choline. Paper electrophoresis indicates that at least two enzymes have been separated from choline-esterase activity during the course of ammonium sulphate fractionation.

A satisfactory method of detecting small quantities of choline-esterase on paper has been evolved. The method is based on the hydrolysis of acetyl thiocholine by the enzyme and the detection of the thiocholine liberated by its ability to decolorize phenol-indo-2 : 6-dichlorophenol. Using this method and also a test method involving weakly buffered solutions of acetyl choline with a suitable

indicator, it has been possible to locate choline-esterase activity on paper electrophoretograms of extracts of *B. germanica*. Under conditions which do not inactivate the enzyme, the bulk of the proteins and the activity do not move appreciably from the point of application. It seems likely from other experience with the enzyme that it is strongly adsorbed to the paper. So far it has not been established whether the hydrolysis of acetyl choline in extracts of *B. germanica* is due to one or more enzymes.

A number of choline esters and analogues have been collected, and preliminary investigations indicate that the properties of the choline esterase activity from *B. germanica* are similar to those of the mammalian enzymes classified as true or erythrocyte choline-esterase. These do, however, appear to be different, and the insect enzyme appears to have a higher affinity for acetyl choline than is usual with mammalian enzymes.

Action of organo-phosphorus compounds on insects

C. Potter, K. A. Lord, Daphne Holbrook and Helen Salkeld have continued their examination of the esterases of insect eggs in relation to embryonic development and the ovicidal action of organo-phosphorus compounds. The possibility that films of pure TEPP inhibit embryonic development at an early stage by a suffocation mechanism has been ruled out by measurements of oxygen uptake. It has been established that the embryonic development of *Pieris brassicae* L., which have a chorion more permeable to water than *Diataraxia oleracea* L., can be stopped at an early stage of development by aqueous solutions of TEPP. When this is correlated with earlier work which indicated that choline-esterase activity only occurred with the later stages of development this provides some evidence that the poison may be obtaining its effect by a mechanism other than that of inhibition of choline-esterase.

It has been decided to include eggs of *Gryllus domesticus* L. in further tests of this nature, since they are highly water permeable, and problems of penetration will be somewhat different. A method of collecting large quantities of eggs by inducing the females to lay their eggs on damp filter-paper has been elaborated. A start has been made in studying their embryology. Tests have shown that these eggs will develop normally when exposed to solutions as acid as pH 3·0 or even lower, so that toxicity of unbuffered solutions of TEPP as strong as 0·1 per cent w/v must be due to effects other than the acidity of the hydrolysis products of TEPP. Preliminary tests with these eggs show the presence of at least three esterases which hydrolyse acetyl choline, triacetin and phenyl acetate respectively.

An attempt has been made to localize the esterase enzymes inhibited by TEPP *in vivo* by use of indoxyl acetate, which is hydrolysed by a wide range of enzymes and then gives indigo, in the presence of molecular oxygen. Three species were used, *T. molitor*, *B. germanica* and *Dysdercus fasciatus* Sign. The insects were dissected and then bathed in an aqueous solution of indoxyl acetate until sufficient colour had been produced in the various tissues. Both normal insects and insects poisoned by topical application of TEPP were examined. In poisoned insects colour had not developed in a number of tissues, notably thoracic muscles. Colour was visible in the nervous system of insects treated with 1 μl. of low

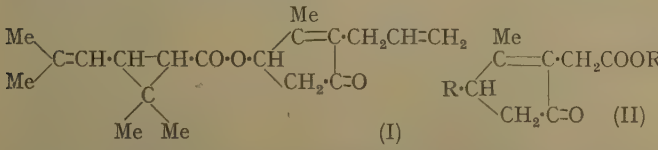
concentrations of TEPP and only ceased to appear with high concentrations (1–5 per cent).

When tissues from normal insects were bathed in 2×10^5 M (approx.) TEPP before the application of indoxyl acetate solution the colour development was inhibited in the nervous, muscular and parts of the reproductive system.

Organic Chemistry

M. Elliott has continued his study of compounds related to the pyrethins.

The most highly active synthetic compound related to the pyrethrins that has been made so far is allethrin (I), the ester of (±)-*cis-trans*-chrysanthemic acid with (+)-2-allyl-3-methyl*cyclo*-pent-2-en-4-ol-1-one (allethrolone).



Since allethrolone is comparatively expensive to manufacture, an investigation has been carried out by M. Elliott to explore the feasibility of using derivatives of 3-methyl*cyclo*pent-2-enone-2-acetic acid as the alcoholic component in esters related to allethrin. Insecticidal data on such compounds would supplement information already obtained on the part played by the side chain of the alcohol in the insecticidal activity of compounds related to allethrin.

3-Methyl*cyclo*pent-2-enone-2-acetic acid (II; R = R′ = H) is obtained from the readily accessible furfurylidene acetone,* and its preparation has been simplified. Reaction of the esters (II; R = H; R′ = ethyl, allyl or phenyl, respectively) with *N*-bromosuccinimide gave compounds whose structure was (II; R = Br; R′ = ethyl, allyl or phenyl, respectively) by analogy with results of previous investigations. Without isolation the bromides were treated with the silver salt of (±)-*cis–trans*-chrysanthemic acid to give the corresponding esters (II; R = (±)-*cis–trans*-chrysanthemyl). The ethyl ester was *ca.* $\frac{1}{10}$ and the allyl ester *ca.* $\frac{1}{4}$ as toxic as allethrin (I) to *Phaedon cochleariae* Fab. adults, but the phenyl ester was much less active. The importance of ethylenic unsaturation in the alcoholic side chain of esters related to (I) was thus again demonstrated. These compounds are the first examples of esters with alcoholic side chains containing a functional group of this type.

The amide, and various substituted amides derived from (II; R = R′ = H), were prepared but failed to give 4-bromo*cyclo*-pentenones (II; R = Br) with *N*-bromosuccinimide. The amide was dehydrated, best with acetic anhydride, to the corresponding nitrile, from which the crude chrysanthemyl derivative was obtained in low yield by the *N*-bromosuccinimide–silver salt route. Unfortunately, it has so far proved impossible to purify the compound sufficiently to give significant insecticidal results.

* Hunsdiecker, *Ber.*, 1942, **75**, 459.

Toxicity and Persistence of Insecticidal Deposits

J. Ward and Eileen M. Gillham have continued their work on DDT deposits. Comparisons between the toxicity of crystalline deposits and of deposits of DDT with Arochlor resin (which remain liquid) have shown that, when tested for contact activity to *T. castaneum*, the ratio of the toxicity of the two types of deposit depends on the time for which the test insects crawl on the deposit. With a 4-hour exposure period, the liquid deposit is 3–4 times as toxic as the crystalline, but with 24 hours, the ratio is only 1·6–2·5. The explanation may be that crystals of DDT which have been picked up by the insects are easily lost, while the viscous liquid deposit is more adherent. During exposure, the crystals lost are readily replaced by others. Once the insects have been removed from the deposit, however, and the adhering crystals have been lost, only the insecticide which has already penetrated into the cuticle remains. With a liquid deposit, a greater proportion of the adhering deposit remains on the insects, and can penetrate before the time for mortality counting.

A programme of work on films of insecticide from emulsions has been begun. After spraying a surface with an emulsion of DDT, the acqueous phase evaporates leaving droplets of DDT solution; in the course of a few hours these begin to crystallize. The form which the crystals take is influenced by the addition of non-volatile, oil-soluble materials to the emulsion before spraying. The effect of these additives can be very great if the emulsion is sprayed on to a glass surface, but is less if the surface is first coated with wax; it is less still if commercial DDT is substituted for pure *pp'*-DDT. The nature of these differences is being recorded by photomicrography, and their influence on the toxicity of the films will be studied.

It has been reported by Martin and Batt (*Rep. agric. hort. Res. Sta., Bristol for 1953*) that when a deposit of DDT from an emulsion or a wettable powder is sprayed on to a leaf (potato or apple), a proportion of the DDT enters the leaf, so that it cannot be removed by washing with solvents, but can be recovered only by drying the leaf, grinding and extracting exhaustively. This was at variance with our own earlier findings with cabbage leaf. On investigation our method of analysis for DDT in extracts of dried cabbage leaf was found to be unsatisfactory. Attempts to remove the interfering substances by the method used by Martin and Batt were unsuccessful, perhaps because of the very waxy nature of cabbage. The interfering substances, however, could be removed by the procedure commonly used for determining DDT in fats, which involves passing a solution in carbon tetrachloride through a column packed with kieselguhr wetted with concentrated sulphuric acid. Using this analytical step, it was found that deposits on cabbage behaved in the same way, a proportion of the DDT being found to be inside the leaf. The amount inside increased with time when the deposit was allowed to remain on the leaf; when the deposit was lost by evaporation, the DDT inside the leaf was lost more slowly. Work has been begun on penetration of leaves from *Graptopetalum paraguayense*, a succulent from which the leaf cuticle can readily be stripped. With this plant, it is hoped to gain information on the depth to which the DDT penetrates the leaf. To simplify this work, a further modification of the analytical method for DDT has been

worked out, using glass cells which give a 1-cm. light-path through 0·3 ml. of liquid; the SP500 spectrophotometer has been adapted to take these cells. The effect of this modification is that the analytical method is now ten times more sensitive, and quantities of DDT down to $\frac{1}{2}$ μg. can be estimated. This makes it possible to work with single leaves of *G. paraguayense*.

Work on the effect of insecticides in the soil, both at Rothamsted and elsewhere, have made it desirable to develop techniques to follow the rate of loss of insecticide from the soil. Janet Samuel was appointed in September to undertake this work. The first requirement is for a method capable of determining lindane (γ-BHC) down to a lower limit of 1 part in 10^8 parts of soil.

The stability of deposits of pyrethrins has been studied by means of a new bioassay technique, depending on knockdown of *Drosophila melanogaster* Meig. The insecticide is sprayed on to squares of cellophane in the Potter tower; these are rolled into cylinders which are slipped into flat-bottomed glass tubes. After putting in the insects, the tubes are closed with glass caps, and are illuminated from above. At intervals the number of insects resting on the bottoms of the tubes is counted. It was found that in the presence of hydroquinone or pyrogallol as an anti-oxidant there was no measurable loss of insecticidal activity after 2 days' storage at 30° C. in the dark. When the deposits were artificially illuminated at an intensity of 600-foot candles about three-quarters of the activity was lost in 2 days. About the same loss occurred when the light was screened through a sheet of plate-glass to filter out any short ultra-violet radiation. The effect of adding various materials to the pyrethrins, aimed at absorbing the long-wave ultra-violet, was studied. Benzene azo-β-naphthol was found to reduce the rate of loss of activity, as has already been reported by Blackith, but *o*-nitrophenol and 2 : 4-dinitro-α-naphthol had no effect, and *p*-nitroaniline increased the rate of loss. So far only purified and decolourized pyrethrum extracts have been used. Work has been temporarily discontinued because of lack of time.

Bio-assay Technique

Margaret Macfarlane has worked out a method for injecting small amounts of aqueous suspensions of insecticides into adult *T. castaneum*. Each CO_2-gassed insect receives 0·125 μl. of suspension by way of a 31-gauge needle inserted through the abdominal tergites. Control kills, measured 24 hours after treatment, seldom exceed 10 per cent.

Pyrethrum and Related Compounds

The constituents of Pyrethrum flowers

Work on the separation of the four known insecticidal principles of extract of pyrethrum flowers by means of displacement chromatography has been continued by J. Ward. An improved column, consisting of four sections of regularly decreasing diameter joined by ground-glass joints, has been made and has been shown to give rather better separations than the earlier continuously tapered pattern. Dinitrophenylhydrazones of the separated constituents

have been prepared. As a chemist has now been appointed by the Kenya Pyrethrum Board to work in London on this problem, it is intended to bring the work here to a conclusion as soon as possible.

The relationship between insecticidal activity and chemical structure in compounds related to the pyrethrins

Esters of allethrolone and chrysanthemic acid. The department is associated with the screening programme sponsored by the Chemical-Biological Co-ordination Centre of the National Research Council, Washington, U.S.A. Fourteen esters, derivatives of either (±)-*cis–trans*(?)-chrysanthemic acid or of (±)-2-allyl-3-methyl*cyclo*pent-2-en-4-ol-1-one (allethrolone) were supplied by the Centre and were tested by M. Elliott and P. H. Needham. The compounds (0·001 ml.) were applied as 2 per cent w/v solutions in acetone to the ventral surface of the thorax of male and female *Phaedon cochleariae* Fab. adults (mustard beetles). None of the derivatives of allethrolone showed any insecticidal activity, but the piperonyl, *o*-chlorobenzyl, benzyl and *p-iso*propylbenzyl esters of chrysanthemic acid gave kills of 100, 78, 63 and 61 per cent, respectively. Since the LD50 for allethrin to these insects under similar conditions is *ca.* 0·02 per cent w/v, the toxicity of the benzyl compounds is relatively low, but the results are of interest, since they indicate that the nature of the alcoholic component in esters related to the pyrethrins is somewhat less critical for insecticidal activity than is that of the acid. The piperonyl ester has been patented as an insecticide and synergist, and a further test has shown it to be one-tenth as toxic as allethrin.

The α- and β-forms of (±)-trans-*allethrin.* M. Elliott and P. H. Needham have investigated the relative potency of the so-called α and β isomers of (±)-*trans*-allethrin (the ester of (±)-*trans*-2 : 2-dimethyl-3-*iso*butenyl*cyclo*propane-1-carboxylic acid with (±)-2-allyl-3-methyl*cyclo*pent-2-en-4-ol-1-one) to adult male and female *P. cochleariae* (mustard beetles). When (±)-*trans*-allethrin is cooled, about half of it separates as a crystalline solid,[2] and this crystalline α-fraction consists of the racemic pair (+)-allethronyl (−)-*trans*-chrysanthemate and (−)-allethronyl (+)-*trans*-chrysanthemate. The liquid remainder is (+)-allethronyl (+)-*trans*-chrysanthemate and (−)-allethronyl (−)-*trans*-chrysanthemate (β-fraction).[3, 4] Gersdorff and Mitlin [5] found the liquid β-fraction to be 4·83 times as toxic as the crystalline α-form to adult houseflies by the Campbell turntable method.

The separation of the α- and β-forms has been repeated, and the β-fraction (still containing some dissolved α) is 9·14 times as toxic as the α-fraction to mustard beetles. This is a remarkably higher difference in toxicity, since all previous values for the relative potencies of esters related to the pyrethrins determined in this department on mustard beetles have shown good agreement with those of the American workers with houseflies.

When these relative potencies of the α- and β-forms to one another and to the mixed α- and β-forms in (±)-allethronyl (±)-*trans*-chrysanthemate are used to estimate biologically the relative proportions of the α- and β-forms present, it is found that the α-form constitutes a little over half the mixture, in agreement with what is

found in the chemical separation. However, Gersdorff and Mitlin [5] estimated similarly that the α-crystalline form constituted only 27 per cent of the mixture, although the necessarily somewhat inefficient separation showed at least 50 per cent of the α present.

Through the generosity of Dr. LaForge, (+)-allethronyl (+)-*trans*-chrysanthemate and (−)-allethronyl (−)-*trans*-chrysanthemate have been available to us, and the pure β-form has been constituted by mixing equal amounts of these two esters. It has been found to be 11·9 times as toxic as the α-form. The possibility that the (+)-(+) ester might synergize the activity of the (−)-(−) ester, and vice versa, has been eliminated by estimation of their potencies separately against the α-form; it is calculated thus that the β-form should be 12·9 times as toxic as the α-form, in good agreement with the experimental result. It is still possible, however, that the (+)-(−) and (−)-(+) forms together in the α-fraction depress each others' activity towards mustard bettles.

The factor rendering this high relative activity of the β- over the α-form remarkable is that from the relative toxicities of (*a*) the α- to the β-isomer and of (*b*) (+)-allethronyl (+)-*trans*-chrysanthemate to (−)-allethronyl (−)-*trans*-chrysanthemate, it should be possible to calculate the effect on potency of changing the optical form of the acid and of the alcohol; the estimation would be invalid, however, if (*a*) synergism or antagonism between the optical isomers of the esters operated and (*b*) if the effect on potency were dependent on the acidic or alcoholic component with which the two forms being considered are esterified. When the results of Gersdorff and Mitlin [3] are analysed in this way the values calculated agree well with those found, viz., that changing the optical form of the alcohol increases or decreases the toxicity of the ester by six times, and a similar change in the acid alters the toxicity by twenty-five times. In our work it has been found that the corresponding values against mustard beetles are 3–4 times and 30–40 times. These figures predict that the β-form should be 3·78 times as toxic as the α-form. Until further data are available, therefore, it is concluded that the most probable explanation of the discrepancy between theory and practice is that depression of insecticidal activity to mustard beetles of the (+)-(−) and (−)-(+) esters occurs when these are mixed.

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Pyrethrum synergists (C. Potter, K. A. Lord, Daphne Holbrook)

The work of comparing the synergistic action of piperonyl butoxide and sulphoxide using adult *T. molitor* as test subject was completed. In order to determine how much specificity of effect occurred with the synergists, the work is being repeated using adult houseflies (*Musca domestica* L.) as test subjects.

Curves on houseflies have now been obtained with piperonyl butoxide. As with *T. molitor*, so with *M. domestica*, the amount of

pyrethrins required to give a selected percentage kill is at first greatly decreased by the addition of synergist, but the effect decreases with increasing amounts of added synergist.

Apart, however, from this general similarity it has been found that much larger proportions of synergists are required to effect a given reduction in the amount of pyrethrins with *T. molitor* than with *M. domestica*.

Insect Resistance to Insecticides

F. Tattersfield and Jill Kerridge have continued their work on this subject.

Work carried out on the possibilities of selecting strains of *D. melanogaster* adults resistant to DDT showed that such was possible, if the selection were carried out for a sufficient period of time. This was shown not to be due to conditioning by carrying out a series of trials upon the adults and their progeny by repeated treatments with sublethal doses of DDT. The effect showed, if anything, that this insect becomes more susceptible under these conditions.

The results obtained, however, suggested that the effect of pre-treatment of the adult insects upon their resistances to DDT was worth quantitative study. The preliminary results showed that insects reared from eggs to adult in the usual way upon a maize-meal porridge containing honey, dead yeast and live yeast, then transferred as adults for a further 6 days to a honey solution alone, absorbed on cotton-wool, were only about one-half as resistant as adults fed for the same period on honey solution and baker's yeast or on the original medium.

A repetition confirmed the greater resistance of the adults fed on honey plus baker's yeast when contrasted with the adults fed on honey alone or left on the old maize-meal porridge medium upon which they were reared. Malt extract added to the yeast and honey had no effect.

In view of these results a series of tests were carried out under similar conditions with a 25 per cent glucose solution with and without yeast (2·5 per cent) and with and without soluble casein (6·25 per cent). Insects reared in the normal way until adult when they were fed on glucose alone, absorbed on cotton-wool, had the same resistance with both males and females as those which continued feeding on a medium of the maize meal, honey and yeast, but the adult females fed on glucose solution and yeast and glucose solution and casein were so resistant that an expression of the comparative result was not obtained. In the case of the male adults the addition of fresh baker's yeast increased the resistance over the glucose medium alone by 2 times, and the addition of casein by $2\frac{1}{2}$ times. The most noticeable feature was, however, that whereas with the addition of yeast, large, healthy larvae and adults were produced from ♂ and ♀ adults fed on this medium, where glucose alone was used, and also with the addition of casein no adults were produced and the larvae, if any, were so minute as to be observable with some difficulty.

The reproductive effect was confirmed by experiments in which glucose solution with addition of (1) live yeast, (2) yeast heated

1 hour in a water bath and (3) biotin, absorbed on cotton-wool were compared. The live baker's yeast and the yeast heated to 100° C. produced many larvae, but with the glucose alone and the glucose plus bioltin no larvae were observed. Many larvae were produced when the adults were kept for a similar period (5 days) upon the usual medium composed of a maize-meal porridge, plus agar, glucose, dead and live yeast, but the larvae seemed larger than in the case of glucose plus live yeast and glucose plus yeast heated in water bath. The differences in resistance to DDT under these circumstances were observable but not nearly so marked.

A series of experiments in which the adult insects (♀ ♂) kept six days on media containing glucose alone, glucose plus live baker's yeast and glucose plus heated yeast were compared. In one series the media were absorbed on cotton-wool and in the other gelled by the addition of agar. It was clear that the nature of the medium has a pronounced effect on the comparative resistances of the adult insects. With cotton-wool as base, although they run in the same order, the differences were not so marked as when agar was used. The differences when cotton-wool and agar were compared at the LC50 were scarcely noticeable for glucose alone and glucose and dead yeast, but were marked when live yeast was added to the glucose, being significantly greater with the agar medium.

These experiments suggested that possibly other factors might prove of some importance. Attempts were made to ascertain whether the freshness of the medium had any pronounced effect, as we had noted in our experiments that insects from old cultures were often less resistant to DDT, and it was by no means clear that this was determined solely by the age of the insect, as adult insects reared on certain yeasts other than baker's yeast, showed a marked decline in *susceptibility* to DDT if transferred every 2 or 3 days to fresh food, when compared with the parent culture on which the insects had remained for some time. The experiment was repeated using baker's yeast on our ordinary medium in which the adult Drosophila were transferred to fresh food 2, 4 and 6 days after emergence. Tests were carried out 6 days after the first transference, the males and females being separated on the day of spraying. The results showed that there was a progressive increase in the LC50, the later the transference or the fresher the food before actual application of DDT. There appeared to be some indication with the females that insects of higher resistance were relatively fewer in number in the case of those insects fed on the older food. The numbers of insects, however, varied ranging from 475 (252 females 223 males) in the first transference, 641 (329 females 312 males) in the second, and 392 (212 females 180 males) in the third. The log LC50 for the females were first transference 2·38, second 2·49, third 2·58 (log mg./1,000 ml.). The log LC50 for the males first transference 2·16, second 2·32, third 2·52 (log mg./1,000 ml.). Age may have proved an important factor in this experiment and it was followed up by one in which the original stock of insects was transferred to fresh food on three separate occasions, separated by 2 days, but at each transference the one previous was also transferred to a fresh food medium. Thus on the day of spraying when the sexes were separated, each batch of insects had had food of the same age. The numbers transferred were :

(1) 677♀ and 596♂ with three transfers, 6–7 days old when sprayed;
(2) 454♀ and 420♂ with two transfers, 4–5 days old when sprayed;
(3) 340♀ and 360♂ with one transfer, 2–3 days old when sprayed.

The log concentration–probit lines were determined.

In the case of the females the log LC50 was (1) 2·69 (2) 2·52. No. 3, however, was so much less susceptible that the LC50 could not be determined. In the case of the males the order for the log LC50 were (1) 2·27< (2) 2·36< (3) 2·43.

In the above cases the sexes were kept together until the day when they were sprayed; in a further experiment they were separated every 24 hours. This, however, did not prevent fertilization, and the numbers of offspring and parents were of the order :

(*a*) Days 1–2 combined parents 422♀ 396♂—Offspring 1,174;
(*b*) Days 3–4 combined parents 769♀ 724♂—Offspring 8,201;
(*c*) Days 5–6 combined parents 571♀ 516♂—Offspring 4,118;

showing an average per female of (*a*) 2·8, (*b*) 10·7, (*c*) 7·2. The female adults gave for the log LC50 in log mg./1,000 c.c. :

(*a*) 2·57> (*b*) 2·37 = (*c*) 2·36 Mean ((*b*) and (*c*)) 2·36.

The male adults gave for the LC50 in log mg./1,000 c.c. :

(*a*) 2·32> (*b*) 2·23 = (*c*) 2·26 Mean ((*b*) and (*c*)) 2.24

The differences are not great, but the order has been reversed from that given by tests where the males and females were separated only on the day spraying was carried out. It is clear in both cases that the population density of the adults was a factor that might affect the results. Different numbers per culture of adult insects were therefore enclosed with their normal food.

(1) 800 (400♀ + 400♂), viable eggs laid 730;
(2) 400 (400♀ only), viable eggs laid 591;
(3) 400 (400♂ only);
(4) 400 (200♀ + 200♂), viable eggs laid 1,242;
(5) 200 (200♀ only), viable eggs laid 1,233;
(6) 200 (200♀ only);
(7) 200 (100♀ + 100♂), viable eggs laid 2,103;
(8) 100 (100♀ only), viable eggs laid 1,818;
(9) 100 (100♂ only).

They were left on the same food for 4 days and sprayed with DDT. The relative susceptibilities as expressed by the log LC50 (mg./1,000 ml.) were :

Females (1) 1·844 > (2) 2·291 > (4) 2·40 = (5) 2·40 = (7) 2·42 = (8) 2·39
Males (1) All killed (3) 2·331 (4) 2·121 (6) 2·34 (7) 2·15 (9) 2·31

It would appear that the population effect was different in the case of the females from that of the males. With the females it appears to depend on the total population of the females and males, if it is

very high, and at a certain level to become independent of the presence of the male insects (No. 4) and to reach a relative constancy (4), (5), (7) and (8). Whereas with the male insects there is a measure of dependence upon the presence of female insects, thus in above table (3) is less susceptible to DDT than (4) and (7) and of the same order as (6) and (9).

There is, however, a change in the steepness of the regression lines. In the case of the females the slopes (b) being (1) 2·1 < (2) 6·7 < (4) 8·5 (5) 8·7 (7) 10·2 (8) 8·2; " b " in nos. (4), (5), (7), (8) is not significantly different.

In the case of the males the slope (b) is as follows: (1) 0 < (4) 3·97 < (7) 4·63 much less than (3) 7·98 < (6) 10·29 > (9) 7·22. Nos (4) and (7) are scarcely significantly different, neither are (3), (6) and (9).

The change in the slope of lines with a tendency to meet at a point at or near the 100 per cent kill would indicate a relatively rapid decrease in the more susceptible insects, with selection. Under the conditions of our tests the population pressure, however, appears with this insect to differ as between males and females; with the former, it depends on the presence of females and with the latter more on the general population.

Some data recently obtained indicate that the presence of larvae in the medium slightly increases the resistance of adults; possibly it is due to an effect they may have upon relative humidity or in breaking up the surface of the medium.

A repetition of the work on the effect of the addition of yeast and of casein to a glucose agar medium, upon the resistance of the adults to DDT was carried out. The change in the resistance was studied using a slightly larger deposit of insecticide and a slightly higher content of acetone in the medium than in the former case, since under the previous conditions the resistance of the females fed on yeast or on casein was too great to be expressed numerically. In this case the reverse result with the males was obtained, no expression for the LC50 for the insects fed on glucose alone was obtainable owing to the almost complete kill obtained at all concentrations tested. The results with the females confirmed those obtained with the males in the earlier tests. The values for log LC50 (log mg./1,000 ml.) and for b (slope of the lines) obtained were as follows (two days after spraying):

(1)	Glucose agar medium	Log LC50	1·86	b 5·2 ± 1·5
(2)	Glucose agar medium + dead yeast... ...	,, ,,	2·01	,, 7·4 ± 1·4
(3)	Glucose agar medium + live yeast	,, ,,	2·11	,, 5·9 ± 0·8
(4)	Glucose agar medium + casein (vitamin free)	,, ,,	2·16	,, 4·3 ± 0·6
(5)	Glucose agar medium + casein (soluble) ...	,, ,,	2·15	,, 4·2 ± 1·0

Susceptibilities to DDT in descending order were:

Glucose > dead yeast > live yeast > casein (vitamin-free) = casein (soluble)

A series of tests carried out before the above tests, in which 100 males and 100 females (per bottle) were used for each test showed that only minute larvae, which died before producing pupae or adults, were produced in the glucose agar medium and no pupae or adults in glucose agar and casein medium, whereas with live yeast

numbers of larvae, pupae and adults were produced after a period of 10 days. A repetition of the experiment with the insects used for testing resistance gave similar results, but there was in this case a greater risk of contamination, and this was somewhat accentuated by the procedure adopted of changing the adults to new food every 2 days, to prevent its exhaustion, and the additional risk of inoculating it by yeasts carried by the insects themselves. There were 3 to 4 replicates for all samples of the medium given in the table above; the results confirmed our previous tests. In one month (25/10 to 25/11) no culture raised on glucose–agar medium produced pupae or adults, although many minute larvae were seen. Only one culture (obviously contaminated) reared on glucose–agar plus casein produced a few adults. Glucose-agar plus baker's yeast [(*a*) alive and (*b*) heated on water-bath for 1 hour] produced many larvae, pupae and adults. It was noteworthy with the baker's yeasts that both larvae and pupae were fewer but much bigger in the case of the heated yeast. Weights were taken. The weights of the adult insects were :

Heated yeast	(1) ♀ 1·3 mg.	♂ 0·83	Live yeast	(1) ♀ 0·49 mg.	♂ 0·36
	(2) ,, 1·3 mg.	,, 0·81		(2) ,, 0·91 mg.	,, 0·65
	(3) ,, 1·3 mg.	,, 0·90		(3) ,, 1·1 mg.	,, 0·68
	(4) ,, 1·3 mg.	,, 0·91			

There were fewer adult insects in the live yeast No. 3, and the pupae took apparently a longer time to emerge. The result is unquestionably due to the great numbers of larvae noted in the cultures containing live yeast,

These results have raised the question whether population pressure amongst the larvae may have a significance for the resistance of resulting adults, and work is now under way to ascertain its significance and the biochemical factors involved.

Insect Rearing

General

Insect species reared during the year included the following species which feed on growing plants : *Acyrthosiphon pisum* Harris (Pea aphid), *Megoura viciae* Buck. (Vetch aphid), *Aphis fabar* Scop. (Black bean aphid), *Myzus persicae* Sulz. (Green peach aphid) and *Tuberolachnus saligna* Gmel.; Lepidoptera—*Pieris brassicae* L. (Large cabbage white butterfly), *Diataraxia oleracea* L. (Tomato moth); Coleoptera—*Phaedon cochleariae* F. (Mustard beetle); Diptera—*Leptohylemyia coarctata* Fall. (Wheat bulb fly) and *Hylemyia antiqua* Meig. (Onion fly).

Stored products and other species reared included : Hemiptera—*Dysdercus fasciatus* Sign. (Cotton stainer); Orthoptera—*Blatella germanica* L. (German cockroach), *Blatta orientalis* L. (Oriental cockroach), *Periplaneta americana* L. (American cockroach) and *Gryllus domesticus* L. (House cricket); Lepidoptera—*Achroia grisella* Fabr. and *Ephestia kühniella* Zell.; Coleoptera—*Oryzaephilus surinamensis* L., *O. mercator* Fauv., *Tribolium castaneum* Hbst., *T. confusum* Duval., *Tenebrio molitor* L., *Calandra granaria* L., *Trogoderma granarium* Everts.; Diptera—*Aëdes aegypti* L., *Drosophila melanogaster* Meig. and *Musca domestica* L.

Main developments this year have been the addition of *H.*

antiqua and *A. aegypti* to the list of insects reared, and the rearing of different strains of *M. domestica* in large numbers. In the New Building two constant-temperature rooms for rearing insects at high temperature are in operation, but rooms for rearing plant-feeding insects and for rearing insects at relatively low temperatures are not yet ready.

Diapause in Leptohylemyia coarctata *Fall.*

M. J. Way has continued work on dispause, which is being done as part of the laboratory rearing programme. This year optimum temperatures for egg development have been fairly closely determined, and it is now possible to store eggs in standard conditions and to control the time of hatching.

Temperature optima vary with the stage of development of the egg. Initially, and before the diapause, a relatively high temperature (about 20° C.) is beneficial. Then a prolonged period of relatively low temperature (below 12° C.) is needed before diapause ends. Hatching will then occur over a wide temperature range (at least between 1° and 30° C.).

Eggs were also kept at constant temperatures from the time they were laid. None hatched at 1° C. (too low for pre-diapause development) or at 20° C. (too high for diapause development), but many of those kept at 7° and 12° C. hatched eventually.

This work is being continued.

Field Experiments

Control of bean aphid (Aphis fabae *Scop.*) *on field beans* (M. J. Way and R. Van Baer)

Nature of the aphid infestation. Work on *A. fabae* infestations on spindlewood, and on time and density of migration to beans was continued on the Rothamsted farm. This year few migrants reached the bean crop and less than 5 per cent of stems was infested in June. There was, however, a rapid build-up during the summer, giving big populations on beans and other plants in August, nearly one month later than in 1954.

Effect of planting date. In a field experiment field beans were planted at four different dates and, for each planting date, yields of unsprayed plots were compared with those of plots sprayed once on 23 June with " Metasystox " (0·05 per cent active ingredient and 100 gal./acre). Aphid counts were made at weekly intervals on all plots from the beginning of June to the end of August, and detailed work was done on the accuracy of the method used for determining the aphid populations. The following table gives the main results of the experiment :

	" Metasystox " treated		Untreated	
Date of planting	Aphids per stem at peak (3–11.8.55)	Grain yield (cwt./acre)	Aphids per stem at peak (3–11.8.55)	Grain yield (cwt./acre)
19 March	100	19·2	90	16·9
6 April	150	18·3	620	13·1
25 April	620	12·0	4170	6·7
13 May *	25	10·5	2190	2·4

* Sprayed twice—23.6.55 and 22.7.55.

It can be seen that this year the single spraying did not give perfect control, especially with late-sown beans. However, the figures for peak aphid populations are somewhat misleading, because they do not indicate the full effect of the control measure early in the season when the plants were relatively very susceptible to damage by the aphid.

Relative importance of biological and chemical control. By using small plots and a caging technique an estimate was obtained of the importance of predators in controlling *A. fabae*, and hence increasing the crop yield. Figures were obtained on the extent to which predators reduce the aphid numbers, and many predators were collected and identified. It was concluded that certain Anthocoridae were of particular importance, but nevertheless biological control was economically inadequate and chemical control was necessary, at any rate on the later-sown crops. Evidence was obtained that, this year, insect parasites and predators of *A. fabae* controlled the aphid more effectively on its winter host (spindlewood) than on its summer host (beans).

Control and laboratory rearing of Leptohylemyia coarctata *Fall., the wheat bulb fly*

Field experiment (R. Bardner and M. J. Way). On Pennells Piece a field experiment has been started that is designed to last for several years. The experimental area is divided into a number of blocks, half of which are bare fallow and half sown with winter wheat (var. Cappelle). Wheat is rotated with fallow, and in this way a permanent infestation of bulb fly is maintained, the adults laying their eggs on the fallow blocks. The experiment will be used to test promising methods of control originating from laboratory and microplot experiments. In the season 1954–55, 5 different treatments were tried in 4 randomized blocks of 6 plots each. These were :

(1) Untreated (2 plots per block).
(2) Seed dressed with technical dieldrin at 2·25 per cent w/w of seed, using a cellulose ether sticker.
(3) 4 per cent dieldrin dust combine-drilled with seed at 120 lb. dust/acre.
(4) Sprayed with parathion on 11 February 1955 at 0·05 per cent v/v active ingredient, 100 gal./acre.
(5) Sprayed with parathion on 7 April 1955 at 0·05 per cent v/v active ingredient, 100 gal./acre.

As the infestation was comparatively light (less than 500,000 eggs/acre), damage was assessed mainly by sampling the plants in the early spring and counting the number of infected tillers.

Results of sampling on 5.4.55

	Untreated	Seed dressing	Combine drill	Early parathion spray
Total tillers	840	511	843	863
Damaged tillers... ...	586	199	255	409

All figures in thousands per acre.

Variance analysis showed that at the 5 per cent significance level there were significantly fewer damaged tillers in the dieldrin treat-

ments than in the untreated plots. The low count of total tillers on the seed dressing plots was probably due to some phytotoxic effect. This is being investigated.

The results of the early parathion spray treatment need confirmation, as there was great variation between replicates. The treatment is being repeated this year. There was, however, a significantly smaller percentage of damaged tillers than in the untreated plots.

A further sample of plants was taken after the application of the late parathion spray. At this time, about a month before pupation, larvae leave the tillers originally attacked and cause further damage by invading tillers as yet untouched. In 1955 this secondary attack was very light, even on the untreated plots, and hence the late parathion spray which was applied to control this attack had little effect.

Grain yields were taken.

	Yield of grain in cwt./acre (85% dry matter)
Untreated	41·0
Seed dressing (dieldrin)	47·2
Combine-drilling (dieldrin)	53·7
Early spray (parathion)	47·9
Late spray (parathion)	38·7

At the 5 per cent significance level all treatments except the late spray treatment gave significantly higher yields than the untreated plots. In addition, the yield from the combine-drilled treatment was significantly greater than that of any other treatment, and was 31 per cent higher than that of the untreated.

In collaboration with the Entomology Department, a microplot experiment was laid down on the Side land, 1st year after fallow, on Broadbalk. It was intended to compare the effect of damage on yields of three wheat varieties. Strips of Holdfast, Squareheads Master and Cappelle were sown, and divided into plots, half of which were sprayed twice with parathion, and half of which were unsprayed. Unfortunately the parathion sprayings did not give complete control, but the experiment showed that the comparative immunity of Broadbalk from serious bulb fly damage is due largely to the sowing of a variety (Squareheads Master) with vigorous early tillering, and that more modern varieties with delayed tillering, such as Holdfast and Cappelle, suffer more seriously from wheat bulb fly attack.

Box Experiments (R. Bardner and M. J. Way). In these experiments known numbers of wheat seeds and wheat bulb fly eggs were planted in a standardized manner in boxes of soil treated with insecticides.

In studies on mode of action, insecticides (dieldrin, aldrin, demeton) were " placed " as bands in the soil in different positions relative to the wheat plants. A band around the stem was most effective, but some kill was caused by insecticides planted well below the seed, which presumably acted by absorption through the roots and translocation to the stem.

Other experiments in which plants grown in insecticide-treated soil were transferred to clean soil before infection suggested that aldrin as well as γ-BHC and parathion acted systematically against

wheat bulb fly larvae. This was confirmed in water-culture experiments. A series of box experiments was done to compare different insecticides for wheat bulb fly control and to study their persistence. The results, which require confirmation because seed germination was poor, suggest that endrin is no more effective than dieldrin or aldrin, and that DDT and parathion are effective as seed dressings, the latter at low dosage.

Laboratory rearing of wheat bulb fly (R. Bardner). As in 1954, large numbers of adults captured in the field were kept in lamp-glass cultures in the laboratory to provide eggs for experimental purposes. Between 15,000 and 16,000 eggs were obtained.

Although it has not been possible to shorten the diapause period of the egg appreciably, the life cycle can be staggered. This was done by freezing eggs in blocks of ice after the completion of the diapause period but before hatching would normally occur. The eggs were stored at a temperature of −8° C. or below until required. Hatching occurred several hours after transference to room temperature. Adults were produced in September from eggs which hatched in June, instead of late January. These flies laid some fertile eggs. Larvae also emerged in November from eggs laid the previous year.

By manipulation of the temperatures at which larvae and pupae are kept, some idea of the optimum temperatures for development of these stages has been obtained. Larvae kept at 20° will develop into adults laying fertile eggs provided the pupae are kept at lower temperatures.

Attempts were made to rear larvae on several artificial diets. These were unsuccessful with 1st instar larvae, but 2nd and 3rd instar larvae lived for 1–2 months at 10° C. on a diet similar to that used for *Drosophila*. Though larvae eventually pupated, growth was not observed, even when macerated wheat plants were added to the diet. It seemed that feeding occurred, because dyes added to the food could be seen later in the gut.

Potato virus diseases

In association with L. Broadbent of the Plant Pathology department, the experiments on the control of the spread of potato viruses were continued by P. Burt.

Good results obtained in previous trials with several insecticides suggested that it might be possible to reduce the number of sprays while still controlling virus spread. In an experiment with the same lay-out as was used in 1954 the effects on the natural aphid population, and on virus spread, of spraying 2, 4, 6 and 8 times with DDT was studied.

Whenever a spray application was due the toxicity to aphids of the insecticide remaining from the previous application was tested, the growth of the crop was followed by measuring the foliage area of selected plants at intervals through the season, and the time at which the virus spread was estimated.

It is hoped that a study of the results from this and from later experiments, particularly of the inter-relationship between rate of growth of the plants, persistence of the insecticide and variation in natural population, will make it possible to minimize the total number of sprays by timing them so as to obtain maximum persistence of the insecticides throughout the season.

Further information about this year's work and about the result of last year's experiment is contained in the report of the Plant Pathology Department.

A small trial was carried out to compare the effectiveness of some high- and low-volume spraying systems in covering potato foliage with insecticide and to compare the persistence of the deposits so produced.

One high-volume and two low-volume systems applied DDT emulsion at a rate of 2 lb./acre of active ingredient to potatoes at 3 stages of growth—just fully emergent (13 June), two-thirds grown (5 July) and mature (15 August). Although at all stages of growth high-volume spraying covered the crop somewhat more completely than spraying at low volume, the persistence of the deposits up to 43 days when tested by confining apterous adult *Myzus persicae* on shoots selected at random from the crop was similar for all systems.

Fungicides

F. T. Last, assisted by Rosemary Hamley and Jane Jackman, has worked on a technique assessing fungicidal action by variations of infectivity rather than germination *in vitro*, and has studied the behaviour of griseofulvin as a systemic fungicide using club-root of brassicae.

Technique to measure infectivity of fungus spores

A local-lesion technique to measure the infectivity of *Botrytis fabae* Sardiña conidia has been developed. A drop of conidial suspension is rubbed over the upper surface of half-leaflets of broad beans (*Vicia faba* L.) with the forefinger, and then the detached plants standing in a test-tube of water are kept in a water-saturated atmosphere at 20–25° C. for 24 hours, when chocolate-coloured lesions are countable.

The number of lesions developing is directly proportional to the concentration of conidial suspension. Suspensions of equal concentration produce more lesions when prepared from young than from old cultures.

The number of lesions developing on different plants varies significantly. Equal numbers of lesions develop on all the leaves of young plants, but significantly more develop on the old than on the young leaves of old plants. The effects of plant variation can be minimized using a suitable experimental design, i.e., Latin square or balanced incomplete blocks.

This technique was used in collaboration with E. W. Buxton (Plant Pathology Department) to determine the effect of ultra-violet irradiation on the infectivity of spores of *B. fabae* and *Uromyces fabae* (Pers.) de Bary and on the susceptibility of broad bean leaves (*Vicia faba* L.) to infection by them (see report of Plant Pathology Department).

Griseofulvin and club-root of cabbages

The effect of griseofulvin, a metabolite of *Penicillium* sp., on the development of club-root is being investigated with I. Macfarlane (Plant Pathology Department). Its effect is linked with the concentration of *Plasmodiophora brassicae* Woron. spores in the soil.

When added to the soil at the time of inoculation and when a range of inoculum concentrations were used varying by a factor of 625 but all giving 100 per cent infection and clubs of equal size (dry weight) in the controls, the highest concentration of griseofulvin gave the greatest reduction in club size, and at all dosage levels griseofulvin was most effective against the lowest concentration of inoculum. The inhibitory effect of griseofulvin on the development of club-root appeared to lessen after 6 weeks.

The rate of increase in size of already infected roots was retarded by the application of griseofulvin to the soil, and there is evidence to suggest that the same effect could be obtained by spraying the foliage. Application of griseofulvin to the soil 2 weeks after inoculation benefited the plants more than applications made simultaneously with or 4 weeks after inoculation.

The retardation in club-root development was associated with increased dry weights of foliage and healthy roots.

Powdery mildew of barley

That powdery mildew can cause a reduction in yield was confirmed. As spraying with lime sulphur was shown not to affect the yield of mildew resistant cv. Haisa II in three seasons, only the mildew susceptible cv. Plumage Archer was sown in the 1955 experiment. Barley was sown on 30 March and 28 April at $1\frac{1}{2}$ and $2\frac{1}{2}$ bushels/acre. Each plot was split, one half being sprayed four times between 24 May and 27 June with 1 in 80 lime sulphur; the other was not sprayed. Plants infected with *Erysiphe graminis* DC. were planted in the unsprayed sub-plots on 19 May.

The unsprayed plants were severely infected and the sprayed plants were lightly infected. The unsprayed plots yielded significantly less grain than the sprayed, 20 per cent less for the early and 27 per cent for the late sowing. The losses are attributable to reductions in : (*a*) yield of grain per 100 years, and (*b*) numbers of ears per plant.

The yields were unaffected by seed rate.

ENTOMOLOGY DEPARTMENT

K. Mellanby

Staff

C. B. Williams, who was head of the department from 1932, retired on 30 June. K. Mellanby was appointed to succeed him.

P. F. Entwhistle (Colonial Office Scholar) and Mrs. Helen Entwistle left the department and proceeded to the West African Cocoa Research Institute in the Gold Coast. Else Haine returned to Germany to a post at the Institut für angewandte Zoologie at Munich. T. R. E. Southwood (Agricultural Research Council Scholar) left to take up an appointment at the Imperial College of Science. Lois M. Cherry, A. J. Cockbain, D. L. Milne (supported by a grant from the South African Government) and M. A. Zaher (Egyptian Government Scholar) joined the department.

R. M. Dobson, B. Johnson and T. R. E. Southwood obtained the degree of Ph.D. of the University of London.

C. G. Johnson visited Germany and the Netherlands in October and read a paper at the Deutsche Pflanzenschutz-Tagung in Kassel on the distribution and dispersal of aphids in the air.

P. W. Murphy returned from Austria, where he had been working in Dr. Kühnelt's laboratory in Vienna. F. Raw continued his period of secondment to the West African Cocoa Research Institute in the Gold Coast.

Insect Migration

(C. B. Williams and R. A. French)

Light traps were worked at Rothamsted until October, to compare results with those obtained by C. B. Williams in Inverness-shire. R. A. French has continued his work on the migration of Sphingida in Western Europe.

Gall Midges of Economic Importance

(H. F. Barnes, Barbara M. Stokes and D. L. Milne)

It was a " good emergence " year for the wheat blossom midges, and under insectary conditions individuals of *S. mosellana* emerged from larvae of the previous thirteen years, most coming from the larvae of 1952. Fortunately there was not complete coincidence of midge-emergence and ear-burst on Broadbalk. However, the annual sampling of the wheat confirmed the prediction made in 1952 that the next outbreak of the wheat blossom midges would occur in 1955 or 1956. The increase of larvae in the crop being about five-fold, there being roughly 27,000 larvae per 500 ears compared with about 5,000 in 1954; this resulted in a 16·7 per cent grain infestation, as against 4·7 in 1954. The unusually long dry spell of weather caused the fully-fed larvae to remain in the ears much longer than usual, in fact until after the drought was broken on 13 August, when the larvae descended suddenly to the soil. This enabled

valuable data to be obtained on the accuracy of the " presampling " technique in use during the last 15 years.

The sampling of Broadbalk has been completed for the 29th successive year. The data for annual infestations 1927–55, as well as tables showing the percentage ear infestation in relation to the percentage grain attack, the numbers of larvae present in relation to the percentage grain attack and estimated loss in yield, have been incorporated into *Gall Midges of Economic Importance, Vol 7: Gall Midges of Cereal Crops*, which was published early in 1956.

Barbara Stokes has continued her biological study of *Mayetiola* spp. living on the stems of cereals and grasses. It had previously been established that one of the species collected at Rothamsted, *M. destructor*, the Hessian Fly, attacks wheat, barley, rye and couch grass as well as some exotic graminaceous plants and that the host plants are interchangeable. Succeeding generations of the midges have been maintained, changing the host plants with different generations.

More *M. destructor* midges have invariably emerged from experiments in which wheat has been used as host plant than from those in which couch grass has been used, although the origin of the parent midges has frequently been couch grass. Similarly, more midges have developed successfully on young plants than on mature eared ones. It has become obvious that more eggs have been laid on the younger leaves than on the older in the four-leaf stage of each host plant tested. Other experiments showed that, whereas the midges oviposited freely on cultivated oats, wild oats (*A. fatua* and *A. ludoviciana*) and on wild wall barley and to a more limited extent on other common grasses, no midges have ever succeeded in completing development on these plants. Subsequent examination of the plants has shown, that although the eggs developed and the larvae hatched, no larva succeeded in establishing itself on any of these plants.

It has been found that there are three flights of Hessian fly a year at Harpenden, although it is possible for the midges that emerge first in each generation to accomplish a fourth generation in 12 months. Little evidence has yet been obtained as to the comparative numerical size of the various flights, but it appears likely that as a rule the first or spring flight (in May) is the largest. This is because a proportion of the larvae of each generation develops slower than the rest and gives rise to adult midges synchronously in the spring with those of later generations. The second flight occurs in July, while the third centres round September.

The percentage of headed straws and non-headed tillers infested by Hessian fly on Broadbalk and Hoosfield wheat–alternate fallow has now been studied for two years, and the results are being written up.

The testing of the host-plant range of *Dasyneura affinis* of violets and *D. violae* of pansies, that have been suggested to be only one species, has been completed by Barbara Stokes. It has been shown that *D. affinis* breeds on *Viola odorata* but not on *V. tricolor* and its variety *hortensis* or on *V. arvensis*, the host plants of *D. violae*. Conversely, it has not been possible to breed *D. violae* on *V. odorata*, the host plant of *D. affinis*. Cross-mating tests between the two midges gave negative results. It has been concluded that *D. affinis* and *D. violae* are distinct species, in

spite of the fact that they cannot be separated on morphological characters.

D. L. Milne is continuing the investigation started last year on the gall midges affecting seed production in clover. The points of immediate interest are whether or not the *Dasyneura* species which is common in white-clover flower-heads is the same species as the well-known *D. leguminicola*, the red clover seed midge, and, if it is not, whether it is identical with *D. gentneri* recently described in the United States from Ladino clover. Biological studies and surveys of incidence are being made in order to assess the economic importance of this white clover midge and, if possible, to find suitable cultural methods of avoiding attacks.

Mr. K. M. Harris, Dr. I. W. B. Nye and Mr. J. A. Bullock each spent a fortnight, preparatory to taking up appointments in West and East Africa, studying gall midges, with particular reference to those of Sorghum inflorescences.

It is obvious from the number of enquiries concerning the wheat blossom midges and the saddle glass midge that the dry summer caused an unusually large number of the larvae of these pests to be removed from the fields during harvesting. Apart from these, the most interesting requests for information concerned the occurrence of *Mayetiola joannisi* on *Poa* on the Rugby Football Union ground at Twickenham and the presence of gall midge larvae in the stems of poppies grown for oil in the Eastern Counties. The latter have been successfully reared but not yet identified.

Numerous consignments of gall midges have also been received from overseas, both for identification and incorporation in the collection. Among the former may be mentioned large series reared from Coccids in Nigeria and from *Stachytarpheta cayennensis* and *jamaicensis* in Trinidad and a *Contarinia* species damaging seed production of *Phleum pratense* in Finland. Among the latter are four recently described species from *Cryptomeria japonica*, *Abies sachalinensis* (*mayriana*) and *Picea jezoensis* in Japan, and three species, two of which have been recently described, from cones of *Picea glauca* in Canada.

Problems of Insect Dispersal

(C. G. Johnson, L. R. Taylor and A. J. Cockbain)

Suction traps

In 1954 accurate measurements of air-flow in all types of suction trap, under all relevant running conditions, were obtained. In 1955 experiments on the proportion of different classes of insects caught under these various conditions were made. It is expected that these measurements will allow a full assessment of errors in aerial density estimation due to varying efficiency of traps. This, it is hoped, will be the final stage in the development of the suction trap.

High-altitude dispersal

The analysis of past trapping at Cardington has continued, particularly on the vertical density gradient of insects in relation to atmospheric stability; on general relations of density to height

during the day and season; and on the speed and frequency of the clearance of insects from the air.

In addition, an exceptionally successful trapping season gave almost continuous day and night records of the vertical gradient and the temperature-lapse rate. For the first time since this work began, attention was paid to all the other insects trapped, as well as aphids, thus broadening the study.

Periodicity and Temperature in the Ecology of *Aphis fabae* Scop.

(C. G. Johnson, L. R. Taylor and A. J. Cockbain)

Moulting rhythms and the period between moulting and flight have been integrated into the general picture of diurnal aerial density change. From these two variables alone in their relation to temperature it is now possible to reconstruct typical diurnal changes in aerial density (including the characteristic double peak) without reference to flight behaviour after take off. These reconstructed curves can be matched with observed density changes as shown by suction traps.

The period between moulting and flight is very important in this respect. Its length depends largely on temperature, especially over the critical range of 16–20° C. This range is undoubtedly also critical throughout the whole ecology of the Aphid, and future work is being planned with this in mind.

Wireworm Studies

(F. Raw, J. W. Stephenson and J. R. Lofty)

The studies of wireworm populations on the ley and arable rotations in Highfield and Fosters have been continued and, after next years' observations, will be concluded. This year's samples indicated a general reduction in the wireworm populations of both fields.

Wheat Bulb Fly Studies

(F. Raw and J. R. Lofty)

The experiments started in 1954 on Pennell's Piece and Broadbalk were concluded after this year's harvest. In the Pennell's Piece factorial experiment designed to investigate the effect of various soil conditions on the choice of oviposition site, plots which had had the highest egg populations the previous year now had the highest proportions of infested plants and gave the lowest yields. The percentages of plants infested varied from 76 for plots with cultivated, rough tilth to 41 for those with uncultivated smooth tilth; the proportionate yields of grain for these plots being 0·86 to 1·0.

The areas of Broadbalk which had been covered with mosquito netting during the oviposition period of the previous year while in fallow had a mean of 3 per cent of plants infested compared to a mean of 12 per cent on the adjacent uncovered areas. The yields of covered to uncovered areas were in the ratio 1·03 to 1. It is thought that had the intensity of infestations been as heavy as that of the previous year the value of this technique as a method of

directly assessing the effect of wheat bulb fly attack would have been more convincingly demonstrated.

Studies on Millipedes

(J. W. Stephenson)

Investigations of the bionomics of millipedes have continued. Data on their activity in the field and on their life histories and feeding habits under laboratory conditions have been obtained, and observations on the direct effects of millipede activity on soil structure have commenced.

A new technique of culturing millipedes in sealed plaster-of-Paris cells is being developed, and, it is hoped, will prove useful to future workers on this and other groups of soil arthropods.

Experiments with "choice-chambers" have shown that some millipedes have decided preferences for particular types of rotted grasses as food, e.g., *Brachydesmus superus* prefers *Dactylis glomerata* to *Poa trivialis*.

Studies on Beetles

(R. M. Dobson and Z. Teofilovic)

Observations on the bionomics of the cabbage stem flea beetle (*Psylliodes chrysocephala* (L)) have been incorporated in a thesis by R. M. Dobson and parts are now being prepared for publication. Preliminary studies of the volume changes in developing eggs of this species were made by Z. Teofilovic in preparation for possible future work.

Analysis of field data showed that the species compositions of populations of crucifer-infesting flea beetles (Phyllotreta spp.) varied not only according to time and place but also between different coexisting adjacent crops. Routine identifications of species of *Carpophilus* (Nitidulidae) associated with stored products have continued, and one new species has been described.

Earthworm Studies

(R. M. Dobson and J. R. Lofty in conjunction with E. Crompton (lately of Soil Survey) and National Agricultural Advisory Service)

The experiments in Lancashire to investigate the rôle earthworms play during the rehabilitation of marginal grassland have continued. In these experiments, after a general application of lime and phosphate to all plots, the effects of dung and balanced artificials at two levels of earthworm population are being studied. At the site near Lancaster, lime was applied during summer 1954, phosphate and dung during summer 1955 and artificials will be applied during spring 1956. Half of each plot was sprayed with lead arsenate to kill worms during November 1955. At Rivington the experiment is one year behind, and so far only lime has been applied. Survey of both sites during spring 1955 showed the principal earthworm at both localities to be *Bimastus eisenii* and the population at Lancaster to be about 15 times as great as that at Rivington (291,000 to 19,000 worms/acre).

In addition to the field experiments, preliminary studies of the life cycle of *B. eisenii* have been carried out in the laboratory.

Effects of Insecticides on Soil Fauna

(R. M. Dobson and J. R. Lofty)

By invitation of Messrs. Plant Protection Ltd., observations are being made on the soil fauna of a field experiment at Haslemere. The experiment, designed to study the long-term effects of BHC applied every year and every 4th year to a four-course rotation (wheat, swedes, barley and ley) has been running for 8 years, and preliminary observations indicate large differences in the fauna of plots under different treatments.

Host Plant Selection in the Wheat Bulb Fly (*Leptohylemyia coarctata* Fall.)

(Barbara M. Stokes)

Experiments were started to test the possible preferences between wheat and the other host plants of the wheat bulb fly.

Wheat Bulb Fly (*Leptohylemyia coarctata* Fall.)

(D. B. Long)

Larval studies

The survey of larval infestations of winter wheat begun in 1954 was continued on Rothamsted soils. The infestation generally was substantially less than that of the previous year, some of the Broadbalk plots having one-tenth of their former level. The greatest infestation was found, as in 1954, in the four-course experiment on Hoosfield, where 69 per cent of the plants contained larvae, 97 per cent having been attacked at the time of sampling involving the destruction of 42 per cent of the existing shoots. The wheat plots of the six-course experiment on Long Hoos 4, and the Wheat and Fallow experiment all carried a slightly lower level of infestation.

The lower larval infestation was partly attributable to the cold, wet autumn of 1954 and partly to the late sowing that the weather enforced. At the time of the hatching of the larvae the gammexane component of the seed dressing used against wireworm had not completely dispersed as normally occurs with an earlier sowing. This provided a residual measure of plant protection, the young wheat bulb fly larvae frequently moving away from attacked plants before fully penetrating a shoot. This, coupled with the small size of the plants, which seldom had more than a single shoot, made conditions unfavourable for the establishment of the larvae. The effect of the adverse circumstances was well shown in the wheat bulb fly experiment set up on Long Hoos 7, where the plants were in the single unopened-shoot stage when sampled in early April, and only 3 per cent of the wheat plants following fallow had been attacked.

In experiments involving the study of movement throughout larval life it was found that a larva which at its largest is seldom more than 0·25 inches may nevertheless traverse a minimum of 33 inches of soil. It was also shown that larvae tended to move

along rows of plants rather than across them. Pot experiments carried out to study the effect of different soil types on larval infestation using freshly hatched larvae showed that the infestation of wheat on Rothamsted clay-loam, although not quite so successful as that on the Woburn sandy-loam, was yet appreciably more successful than that on the Fen peaty-loam. These studies are being continued.

Adult studies

Field observations on the adult fly were continued. The adult population closely followed the lower level of larval infestation, the numbers obtained by regular sweeping being about one-tenth of those caught in 1954, but in contrast to the former year, in 1955 females predominated. The diurnal movement of flies to and from the crop was again noted, the greatest number of flies always being taken at 6.0 a.m. B.S.T. In this respect the females were noted to differ in behaviour from the males. Flies tended to return in the evening to the lee side of the whole crop rather than to the emergence plots. The lower level of infestation prevented the successful conclusion of experiments on movements of the fly population.

A study of oviposition sites planned in an experiment on Long Hoos 7 failed owing to the generally low level of infestation, but it was found that flies tended not to lay eggs near a vertical screen such as that provided by an adjacent stand of crops or a hedge. The effect of such a screen 3 feet high was found to extend up to 6 feet from its base. Experiments begun the previous year on the oviposition rhythm were continued in the laboratory with freshly caught flies which showed the peak laying time to be in the 2 hours before dusk.

Eggs

Studies begun in 1954 on water relations between the egg and its environment during development were continued, and in this respect the effects of certain ovicides are being investigated.

Effects of Population Density on Insects

(D. B. Long)

The work on the effects of population density on larval forms has been continued, and cultures of the sawflies of pine, larch and gooseberry have been established in order to extend the field of the work. A study has been started (with M. A. Zaher) on the effects of the population density on adult lepidoptera.

During August R. Cayrol from l'Institut National de la Recherche Agronomique of Versailles spent a month at the laboratory in connection with his work on population fluctuations in Lepidoptera.

Photo-colour response in lepidopterous larvae

The study of the colour changes in the spots of the older larvae of the Emperor Moth (*Saturnia pavonia* L.) when exposed to light has been continued. It has been found that the response is dependent on low energy wavelengths at the red end of the spectrum between the limits of yellow and infra-red which in themselves do not produce a colour change.

Forest Soil Investigations

(P. W. Murphy)

From June 1954 to September 1955 P. W. Murphy worked with Professor Kühnelt at the Zoological Institute of the University of Vienna; the visit was made possible by a grant from the Forestry Commission.

Field work was concerned mainly with an investigation of the fauna occurring in forest sites on rendzina soils in the Vienna Woods close to the city. The experimental sites have been used as sources for material in a number of investigations carried out at the Zoological Institute, and on this account there is a considerable amount of information available concerning faunal composition, etc. The object of the study was to determine faunistic changes taking place during the development of the rendzina profile. In addition, a number of undisturbed samples of characteristic profiles have been collected in various parts of Austria for Dr. D. A. Osmond of the Soil Survey of England and Wales.

During the winter months time was devoted to the development of a culture method suitable for small soil-inhabiting animals such as the Acarina, and a new technique has been devised which is proving very successful for biological studies in the laboratory. Up till now there has been no really suitable culture method to provide the necessary environmental conditions required by these organisms, and it is hoped that it will be of value for studies of food habits, etc., of oribatid and other soil-inhabiting mites.

An English translation of Professor Kühnelt's book *Bodenbiologie mit besonderer Berücksichtigung der Tierwelt* is almost complete; it incorporates Professor Kühnelt's revisions of the original text.

BEE DEPARTMENT

C. G. Butler

General

Throughout the year the research work of the department has been continued along the lines mentioned in recent reports. In addition, several members of the department have continued to serve on a number of Committees and have also given lectures and demonstrations at meetings of Scientific Societies, Beekeepers' Associations and other organizations.

C. R. Ribbands has been awarded the Sc.D. degree of Cambridge University, and Doreen Gibbons and Inge Riedel have joined the scientific staff. T. Palmer-Jones of New Zealand has been a guest in the department for about five months, during which he made a detailed study of bee research methods and practical beekeeping in this country.

Bee Behaviour

Foraging behaviour

C. R. Ribbands, in collaboration with Professor J. B. S. Haldane, has been conducting an experiment designed to assess the accuracy with which foragers communicate the whereabouts of food crops to other members of their colonies. As this experiment progressed it became clear that the use of body odour was playing an unexpectedly large part in attracting companions to the immediate vicinity of the foragers. If conditions are propitious it is hoped to continue this work during 1956.

Conclusions that have hitherto been reached on the practicability and efficacy of attempts to cause honeybees to visit the flowers of selected crops which require pollination have been conflicting. J. B. Free has, therefore, been attempting to obtain answers to some of the problems involved. Two of the questions he has been studying are : whether the nectar and pollen already stored in the combs of a colony influence the choice of plants from which its members will collect food, and whether syrup feeding of colonies results in any increase in the proportion of pollen to nectar subsequently collected by their members.

Swarming

Investigation of the factors controlling the incidence of swarming by honeybee colonies has been continued by J. Simpson by an analysis of records made by beekeepers during their routine inspections of colonies during the swarming season. The following tentative conclusions have been reached.

The proportion of colonies which produce queen cells in the presence of a laying queen, and therefore are possibly preparing to swarm, varies from year to year. Smaller, but still significant, variations occur between apiary sites. These variations appear to be related to environmental differences, not to changes in methods of

management or to the genetical characteristics of the colonies of bees concerned.

The onset of queen cell production in individual colonies occurs, as a rule, between the middle of May and the end of July, and is most frequent around midsummer.

The bees in over half of the colonies which begin to produce queen cells eventually cease to do so, without swarming, with no other treatment by the beekeeper than regular removal of the queen cells produced. It is uncertain whether any colonies in which queen cells are found will in fact swarm even without such treatment, since observations of experimental colonies in which queen cells have been left have shown that in a number of cases transient queen cell production takes place without swarming. Since amongst colonies which produce queen cells the proportion which fail to swarm, though they receive no other treatment than regular queen cell removal, is greater after midsummer than before, it is probable that observations of queen cell incidence fail to give an entirely reliable index of the relative incidence of swarming at different times.

Colonies whose queens are replaced before the end of June, by new ones reared in the current season, are much less likely to produce queen cells during the rest of the season than colonies which are not re-queened in this way. However, owing to the uncertain relationship between swarming and queen cell production this does not necessarily mean that re-queening early in the season with a current season's queen will reduce the tendency of a colony to swarm.

The organization of social life

The results of C. R. Ribbands's food-sharing experiment, which was carried out in 1954 in order to determine the distribution amongst the members of a colony of one honey-stomachful of radioactive ^{14}C sugar syrup collected and carried into the colony by a single bee, are still being analysed. Most of the routine work has now been completed, and it is hoped that the results will be published during 1956.

C. R. Ribbands considers that food sharing provides the network of communication which is the basis of social life in the honeybee community (164).

One of the functions of food sharing is, as he has shown, the production of distinctive community odours, another, as C. G. Butler has recently shown (179), is the widespread distribution of queen substance amongst the worker bees of a colony.

Queen substance plays a vital part in the social organization of the honeybee community, since, provided it is obtained from the queen in sufficient quantity and shared out amongst the workers of her colony as normally happens, it prevents development of the worker's ovaries, as well as inhibiting the production of all kinds of queen cells. Failure, or inadequacy, of the supply of queen substance in circulation amongst the members of a colony results in queen cell production and worker ovary development.

Effective extracts of queen substance have now been obtained from queen honeybees, even from long-dead ones, in various organic solvents (179), and C. G. Butler and Dr. D. B. Carlisle, of The Laboratory, Plymouth, have demonstrated that extracts of the sinus glands of female prawns (*Leander serratus*) are effective in inhibiting

ovary development in worker honeybees, and that honeybee queen substance can also act as an inhibitor of ovary development in prawns (180). C. G. Butler has also been able to demonstrate that honeybee queen substance and ant queen substance (extracted from queens of *Formica fusca* and *F. rufa*) are interchangeable. It appears possible, therefore, that a single ovary-inhibiting substance is present in different Arthropods, and that in some of the social insects this substance has acquired the additional function of controlling queen production.

It is not yet clear whether queen substance reacts directly upon the metabolism of a recipient bee or whether it merely acts as a " trigger mechanism " and results in the release of a hormone which inhibits ovary development. If queen substance only acts as a trigger mechanism it is quite likely that still other releasing mechanisms exist.

These investigations are being continued, and it is hoped to publish further results shortly.

An investigation of the stimuli leading to food exchange between the worker bees of a colony has been made by J. B. Free. As was anticipated, he has found that bees who are offering food to other bees, or begging for food from them, usually direct their offering or soliciting movements towards the heads of other bees; indeed, excised heads alone are sufficient to elicit either of these reactions. He has also shown that although the colour and shape of a bee's head play little or no part in eliciting either of these responses, the scent of a bee's head is an important stimulus in doing so. Furthermore, it has been found that the excised heads of bees taken from the same colony as the experimental bees, whose reactions are being studied, are more effective in releasing both these responses than are the heads of bees from other colonies. It therefore appears that colony odour may be important in this respect.

Free has also shown that the antennae provide a contact stimulus to both reactions and that their effect can be simulated by means of artificial antennae.

Whereas movement appears to play no part in releasing the begging response of a bee, it plays a significant rôle in releasing offering behaviour. Both begging and offering are innate reactions, the precision of which shows improvement with age, independently of conditioning.

General Research

Behaviour of drones within the hive

As a part of the bee breeding research programme J. B. Free has begun to study the behaviour of drones inside the hive, using marked individuals of known ages. He has found that worker bees feed drones of 2 and 3 days old the most frequently, and also that drones of this age are fed for longer on each occasion and therefore presumably receive more food than drones of other ages. The number of times a drone is fed decreases rapidly as he becomes older. The ages of those worker bees who were seen to feed drones varied between 2 and 26 days, but workers of 4–6 days old were especially concerned. Drones of 4 days old and more will take honey for themselves from storage cells, but younger ones do not appear

to do so. Drones seem to spend about three-quarters of the time that they are in the hive more or less stationary on the combs, but the periods of inactivity are frequently interrupted by short periods of movement over the combs. The age of a drone appears to be important in determining the behaviour of the workers towards him. For instance, even when in late summer the older drones of a colony are being driven from their hive by the workers, the younger drones present may not be treated in this way at all, but, on the contrary, may still continue to be fed by the workers.

Queen introduction

The studies on the problems involved in queen introduction mentioned in previous reports have been extended, partly with the help of members of the Bee Research Association and other bee-keepers. An analysis by C. G. Butler and J. Simpson of the results obtained to date (full details of which it is hoped to publish shortly) suggest :

(*a*) That when young, or old, virgin queens were introduced directly (without caging) to colonies from which young (1–5 days) or old (12–28 days) virgin queens had just been removed, comparison of the results showed that it was much easier to introduce a queen into a colony from which a similar queen had been removed than into a colony from which a dissimilar queen had been taken.

Between old, laying, queens and old, virgin, queens a similar but less extreme pattern of behaviour was observed, whilst with other combinations of queens of different categories (which included newly mated queens who had just begun to lay eggs) the difference in the proportion of successes between introductions of like and unlike queens were mostly non-significant. It is suggested that from the point of view of introduction to colonies, young and old virgin queens are sharply differentiated, while the other categories of queens studied possess intermediate characteristics in this respect.

(*b*) When mated, laying, queens were interchanged directly and the treatment given to them by bees of the recipient colonies was noted, it was found that the queens were more frequently molested by bees belonging to bad-tempered colonies than by those of good-tempered colonies.

(*c*) An analysis of the results of queen introductions made in the course of normal beekeeping practice, using a special cage in which the queen was confined without either food or attendants, showed that mated, tested, queens could be introduced to colonies from which laying queens had just been removed with a probable average success of at least 90 per cent. Virgin queens could similarly be replaced by mated, tested, queens with a probable success of at least 80 per cent.

The size of colony to which a queen was introduced appeared to have little, if any, effect on the likelihood of her acceptance.

Introduction of virgin queens by means of the cage

method to colonies from which laying queens had been removed was less successful and requires further study.

(*d*) The proportion of successful introductions varied significantly in the different summer months, and was actually lowest in June. Difficulty was also found in introducing mated, tested, queens to colonies which were or had recently been rearing queen cells. Since June is the month when queen cells are most frequently present in colonies (see section on swarming), these two observations may be related to one another.

One of the results of food sharing amongst the adult members of a colony is the production of distinctive colony odours, and experiments by C. R. Ribbands involving the transference of queens between colonies which have been foraging on heather and colonies which have not, show that these distinctive colony odours play a part in the difficulties of queen introduction.

Wax-moth

It has been observed by L. Bailey that infestation by the Lesser Wax-Moth (*Achroia grisella*) was eliminated in combs which were fumigated with acetic acid vapour for the control of Nosema and Amoeba diseases. Adult and larval wax-moths were killed within 24 hours. Some fumigation experiments with the eggs of the Greater Wax-Moth (*Galleria mellonella*) and of the Lesser Wax-Moth showed that they were killed after exposure to acetic acid fumes for 12–24 hours at 59° F. Over 2 days' exposure at this temperature were required to kill their eggs with *p*-dichlorobenzene.

Bee Diseases

Nosema disease

Attempts to eradicate Nosema from most of the Department's colonies were begun by L. Bailey in 1954. The bees of each colony were transferred on to combs sterilized with acetic acid or formaldehyde as described in the last Annual Report. In April 1955 only 7 per cent of the colonies showed any infection. This figure includes colonies which had not been treated for various reasons, and compares well with the figure of 90 per cent of colonies infected in 1952, the year before research work on the control of this disease was begun.

The remaining infected colonies have now been treated, and all combs that are not in use are now sterilized with the fumes from 80 per cent acetic acid as a routine measure before they are re-used. It is hoped that the disease will be eliminated by these simple precautions.

Acarine disease

L. Bailey and Elizabeth Carlisle have demonstrated by means of field tests that the mite *Acarapis woodi* can be eliminated from infected colonies by two applications of any of the following acaricides: di-(*p*-chlorophenyl)-methyl carbinol (" Dimite ", " P.K."), ethyl di-(*p*-chlorophenyl)-glycollate (" Chlorobenzilate ", " Folbex ") and *p*-chlorophenyl, *p*-chlorobenzene sulphonate (PCPCBS, the

active ingredient of "Ovotran"). These acaricides were applied as smokes. The weather was warm (55–70° F.) at the times of application, and the disturbance caused in two out of eight colonies which were treated in the evening following a heavy nectar flow caused the deaths of several thousand bees. The queens were not affected.

It seems likely that treatment with these acaricides can best be carried out during warm weather, in early summer, before the main nectar flow begins, as treatment is distinctly less efficient when applied during cool (40–60° F.) weather.

Whereas PCPCBS was still the only acaricide treatment which produced rapid ovicidal effects in further laboratory tests, it proved no more efficient than the other acaricides in field trials during 1955. The ovicidal effect, although significant, is probably too slight.

It is probable that much more efficient acaricides of these types for use against *Acarapis woodi* are to be found. Even phenyl salicylate has recently been found to be highly effective, but it may be too toxic to bees. Methyl salicylate also has significant effects, but again it appears that its toxicity to the bee reduces its practical value. Nitrobenzene, probably the active constituent of Frow's mixture, was found to be toxic to bees but not to mites when applied as a smoke. Tests with Frow's mixture applied in the usual fashion during the winter of 1954–55 showed it to be very effective against the mites. But controlled experiments demonstrated that all the infected bees also died in treated colonies in the latter part of the winter. This proved to be disastrous to the heavily infected colonies which were treated, but such an effect would be acceptable in the cases of colonies which were only lightly infected.

European Foul Brood

L. Bailey has continued to study the natural cycle of infection. All the bees from infected colonies were transferred to uncontaminated combs in the late summer of 1954, when the disease had practically disappeared for the season. During 1955 these experimental colonies became very strong, but a few larvae that had died from the disease were first found in mid-June, and infection rapidly increased and reached a peak at the end of the month. As there is no evidence that any stage in the life history of the organism responsible for this disease occurs in the adult honeybee, it is considered likely that in these cases contamination was carried mechanically by the bees on to the clean combs to which they were transferred in 1954. In the control colonies dead larvae were found in mid-April and the infection increased less abruptly, but it also reached its peak at the end of June. The control colonies were by this time markedly weaker than the experimental colonies. Despite the different rate of development of infection and the different effect it had on the strengths of the control and experimental colonies, the signs of infection began to disappear from all colonies simultaneously and at the same rate, and by mid-August were scarcely detectable. The ability of this disease to develop in very strong colonies (each of which eventually gave yields of surplus honey of 50–100 lb.) suggests that the statements of some workers that the maintenance of strong colonies obviates this disease are incorrect and that,

although the effect of the disease may be masked and easily pass unnoticed, it does not suppress its development.

Work has been continued on the isolation of "*Bacillus*" *pluton* and on the effects of antibiotics and sterilizing agents upon the course of European Foul Brood disease.

STATISTICS DEPARTMENT

F. YATES

Two members of the scientific staff left during 1955. G. E. Hodnett, the Colonial Office Statistician attached to the Department, has been appointed to the post of Statistician to the Regional Research Scheme based on the Imperial College of Tropical Agriculture, Trinidad, and Muriel E. Davis left to take up a post as Secretary to the Experimental Husbandry Farms of Reading University.

New appointments were: H. R. Simpson from Cambridge University, J. C. Gower from Cambridge and Manchester Universities, Mary G. Hills from the Central Research Establishment of the National Coal Board and Marjory G. Morris, who has in the past worked in the Department of Tsetse Control, Gold Coast.

Thirteen temporary workers were accommodated in the Department during the year, twelve of them from various countries of the Commonwealth.

THE ELECTRONIC COMPUTER

Arrangements have been concluded with the National Research Development Corporation for the Elliott 401 to remain at Rothamsted for a further period of 5 years, half the time of the machine being, as before, at the disposal of the National Research Development Corporation. Apart from a period in the early part of the year, when a faulty batch of valves gave rise to considerable trouble, and some trouble with the disc during the very hot weather, the machine itself has for the most part behaved well. The same cannot be said of the ancillary equipment, especially the tape reader and the typewriter.

During the year a good deal of work has been put into the reorganization of the input and output, and considerable progress has been made. The computer now uses a common input and output code in place of the two separate codes used previously. This has required a major electronic modification. The new code has the special feature that characters can be checked against errors in either reading or punching. When an error has been made during the input of information, the machine will stop. Errors in the output will lead either to a hold up on the typewriter or to the printing of a non-numerical character on the teleprinter. The programmer has the option to use either checked or unchecked input and output.

Plans to build a further tape reader have been abandoned in favour of replacement by a Ferranti high-speed reader, and steps are now being taken to secure one of these. A new Creed high-speed punch has been obtained to replace the present makeshift punch as the main output of the machine. This should be in operation very shortly and will nearly double the output speed of the machine. Tape from it will normally be fed directly to a teleprinter, thus obviating much of the present need for the typewriter.

A new and much improved keyboard punch and teleprinter unit has also been obtained. This provides a printed record of all tapes as they are punched or reproduced, a feature which greatly facilitates the checking and editing of tapes prepared for the machine. Previously, input tapes could only be checked by reading the tape visually, by duplicate punching and visual or machine comparison, or by printing out via the machine. All these methods were crude and grossly inefficient, and led to much waste of operator and machine time. The old tape equipment is now being modified and reorganized so as to provide further punching and printing facilities to deal with the increasing load of productive work. The whole of our tape equipment can be utilized much more efficiently and rationally now we have a common input and output code.

The other main line of development with which we are most anxious to press ahead, namely input of data from punched cards and output of intermediate results back to cards for further processing by Hollerith equipment, has made slower progress than was hoped owing to numerous difficulties in obtaining the required equipment. The difficulties with regard to input from cards are now, however, well on the way to solution, though output to cards is not so well advanced.

Apart from the improvement of input and output facilities, the main task of the year has been the writing of programmes for various types of statistical analysis. Yates, Healy, Lipton, Rees, and since their arrival, Gower and H. R. Simpson have been mainly concerned with this. Experience has shown that to be of real use in routine statistical analyses, the machine should carry out the whole of the analysis, being presented with the raw data and producing typed copies of the results in the required form. Thus in the analysis of replicated experiments the preliminary conversion of yields and calculation of such quantities as yields of sugar from yields of dirty roots, dirt tares and sugar percentages is performed on the machine, which then carries out the analysis of variance and prints out the analysis of variance table, together with the necessary tables of mean yields and their standard errors. An added feature, which is not practicable with desk computers, is the calculation of the residuals, i.e., what is left after allowing for effects of treatments and blocks (or rows and columns of a Latin square). These residuals are very useful in spotlighting the sources of excessive error. Residual sums of products (for covariance analyses) can also be obtained when required, and missing data (" missing plots ") can be dealt with by means of small supplementary programmes (201).

Programmes of this type are necessarily fairly elaborate, and are practicable only for designs which are in common use. Those at present available are for randomized blocks (up to 64 blocks or 64 treatments, with a maximum of 128 plots), Latin squares (up to 10×10), the $3 \times 3 \times 3$ factorial design in blocks of 9 with a single replicate, and one form of randomized blocks with split plots (this last being for an extensive series of variety trials containing N as an additional factor, carried out by the National Institute of Agricultural Botany in 1955).

The following analyses of experiments were carried out on the computer during 1955 (each variate analysed being reckoned as one unit) :

	Randomized blocks	Latin squares	3 × 3 × 3
Rothamsted, etc.	187	121	—
National Agricultural Advisory Service...	248	12	16
National Institute of Agricultural Botany	250	—	—
	685	133	16

Another standard type of statistical analysis for which a programme giving a complete solution has been written is the fitting of probit lines. This provides the equation to a fitted probit line together with the LD50 and its fiducial limits. A χ^2 value measuring the goodness of fit of the line is printed, and allowance can be made for heterogeneity and non-zero response in the controls. A similar programme for fitting a probit plane has also been prepared. These programmes have proved of considerable value to the Insecticides Department, particularly on account of the speed with which the work can be completed.

For the less standardized types of statistical analysis the parts which are of standard form and which require heavy computation can be carried out on the machine. Much multivariate work is of this type, and the following general programmes for such work have been written :

Sums of squares and products
Multiple regression
Matrix inversion

These programmes have already been used on multivariate work of various kinds.

Other miscellaneous programmes written for special purposes during the year are :

Calculation of a discriminant function (for tuberculin testing of cattle).
Asymptotic regression (used for fitting growth curves of children and the study of response curves for fertilizers).
Solution of the differential equation $\nabla^2\phi = 2e^{\phi}$ (required by the Physics Department in the study of the properties of colloids).

The programming of various types of Fourier analysis required by the Pedology Department for their crystallographic studies is now in progress.

A programme for the solution of coupled non-linear differential equations was written for an important piece of work on non-linear regenerative extraction of synchrocyclotron beams, reported by Dr. K. J. Le Couteur and Lipton (205). This work was begun while Lipton was at Liverpool University. All the necessary computational work has been carried out on the Elliott computer.

The study of sampling errors, which is required in the evolution of satisfactory sampling techniques, will be greatly aided by electronic computation. A programme has already been written for the determination of sampling errors in samples of various types from serial data. This was required for the study of sampling errors in nutritional surveys (193).

While the writing of programmes does not occupy machine time,

the associated testing necessary to locate and eliminate all errors can consume very substantial amounts of both machine and programmers' time. We have given a good deal of thought during the past year to devising ways for lightening the programmers' task, both by reducing the actual work of coding, improving the accuracy of the initial programme and speeding up the location of errors. One obvious way is to use the machine to carry out the simpler parts of its own programming. In the order code for the Elliott, as in most computing machine codes, there are a number of minor arithmetical conditions between the different parts of the order which have to be satisfied. The code is also of the type in which each order specifies the address of the next order, so that the orders can be dotted about the store in any manner that appeals to the programmer. This enables speed of operation to be increased (so-called "optimum" programming), but obviously leads to more complex programming than do codes in which all the orders are located serially in the store in the order they are to be obeyed. These details can now be relegated to the machine by means of an automatic programming routine. This enables the programme to be written in a simplified code, without specification of store positions. The routine then assigns timing numbers and store positions so that all the required arithmetical conditions are satisfied and the timing is reasonably optimal, draws attention to any blunders on the part of the programmer that can be detected from internal evidence, prints a diagram of occupied store positions and punches out a final order tape. This automatic programming routine has already proved its value, both in saving programmers' labour and in producing programmes which contain far fewer errors. In response to developing needs it has recently been modified in order to deal with larger programmes, and programmes written on more than one "Track 7". (See Lipton (208) for a description of this feature.)

Two further routines of considerable use in checking and correcting programmes have been written. The first is a fault-finding routine which enables a computation to be interrupted at any point in the programme and the contents of the registers and any chosen store positions printed out with subsequent return to the programme at the correct point. The second is a routine for printing out a programme in logical order. This enables a programme which has been considerably corrected or modified to be reprinted in logical order, and also reveals any errors in addresses which lead to errors in the logical order. (These errors are in fact usually the most troublesome to locate, since the machine "runs out of programme" and may indeed mutilate its programme in the process.)

Design and Analysis of Experiments

The paper on the amount of experimentation (Grundy, Healy and Rees (197)) has been completed and presented at a meeting of the Research Section of the Royal Statistical Society. This deals with the case in which it is necessary to decide, after a preliminary set of experiments, whether to recommend one of two alternative processes or to carry out a further set of experiments, and if so what the size of this further set shall be, assuming that on its completion a decision

must be taken. The work has aroused considerable interest amongst statisticians concerned with empirical experiments to test out new processes.

Work has continued on the reorganization of the long-term and classical Rothamsted and Woburn experiments. Patterson has been particularly concerned with this work and with the design and analysis of long-term experiments at Rothamsted and elsewhere. Boyd has co-operated with W. B. Haines in summarizing the factory series of sugar-beet fertilizer trials, and a report on this work is now almost complete.

There has been a growing volume of routine work on the design and analysis of field and laboratory experiments for Rothamsted and other research stations and for the National Agricultural Advisory Service. Reorganization of the computing side has been effective in considerably speeding up the production of the annual report of the results of the Rothamsted and Woburn field experiments. The electronic computer has played an increasing part in the analysis of standard types of design.

Miscellaneous work includes a paper by Hodnett on the analysis of an unusual experimental design (204) and one by Healy on the analysis of a factorial experiment with additional treatments (199). Hodnett has also discussed the number of levels that are best included in fertilizer trials designed to establish the response curve (203). Patterson has investigated the fitting of response curves of the exponential type (209). After some delay the report by Yates and Finney to the Government of India on statistics in agricultural research has now been published by the Food & Agriculture Organization of the United Nations (215).

The Department is represented not only on the Crop Experiments Sub-Committee of the Experimental Husbandry Committee of the Agricultural Improvement Council but also on the Animal and Poultry Sub-Committees, and has recently established closer links with the Agricultural Research Council Statistics Group at Cambridge, which is mainly concerned with animal problems. Work on the collation of the results of experiments on antibiotics for pigs is substantially complete, and a paper on the results of 3 years of a poultry experiment at Gleadthorpe Experimental Husbandry Farm is in course of preparation in co-operation with members of the National Agricultural Advisory Service. A report on the results of five experiments at three different laboratories on the assessment of bacterial populations in soil is being prepared with the Provincial Advisory Bacteriologist, Bristol, and a paper has been completed on the feeding of fodder beet to pigs (212). Westmacott has continued in charge of this work.

We co-operated with the National Institute for Research in Dairying, Shinfield, and the Advisory Bacteriologists of the National Agricultural Advisory Service in a series of trials to compare the standard hypochlorite disinfectant with some new detergent sterilizers that had been submitted to the Ministry of Agriculture, Fisheries and Food for approval (Leech). Leech also completed the analysis of a large experimental assay of new tuberculins on cattle and tests of their power to discriminate between tuberculous and tubercle-free cattle.

A fortnight's course for members of the National Agricultural

Advisory Service, mainly on experimental design and analysis, was given in the spring. Sixteen N.A.A.S. officers attended.

Surveys

Surveys of fertilizer practice were carried out by the Provincial Soil Chemists of the National Agricultural Advisory Service in four districts of South-West England and in South-West Lancashire, and analysis is in progress. A report on the 1954 surveys has been prepared and will appear shortly. Eight of the districts surveyed during 1954 were previously surveyed in 1951; the results show average increases of 0·04 cwt. N and 0·05 cwt. K_2O/acre crops and grass in these districts. Phosphate consumption had changed very little except in two districts. The proportionate increases in use of fertilizers were greatest on grassland.

Church has summarized information from fertilizer surveys (1950–54) on the manuring of cereal crops (192). More than a third of the cereal acreage in England and Wales receives no nitrogen fertilizers, and the average dressings given are 0·25 and 0·35 cwt. N/acre, compared with a calculated optimum dressing of 0·6 cwt. N/acre. Profitable increases in the use of nitrogen on cereals might increase total cereal yields in England and Wales by about 6 per cent. Average potash dressings are about optimal, on the available experimental evidence, but phosphate fertilizers are used on much of the cereal acreage at rates which cannot be profitable. At variance with current advice, as much as a third of the nitrogen used on winter cereals is applied in the seedbed in autumn, and use of complete fertilizers results in the wasteful application of phosphate and potash to winter cereals in spring top dressings.

On the animal side, collaboration between F. B. Leech and Dr. F. W. Withers has continued in the survey of diseases of dairy cattle. Samples of farms from Devon, Salop, Yorkshire (W. Riding), and a region in Ayrshire and Lanarkshire have been supplied to the field workers. Results obtained in the 1953–54 season have been analysed. A combined report on the two years' work is planned. The results of a second survey of losses in pregnant ewes in Yorkshire, carried out on the same farms as the first survey, are being analysed by Leech and will be written up with Dr. K. C. Sellers, who carried out the survey. Leech has also advised on the analysis by punched-card methods of the results of a survey of animal husbandry and diseases now being carried out in Northern Ireland. The analysis will be done in Belfast.

Emily P. Simpson and Lessells have examined data on the errors associated with soil sampling for chemical analysis at the request of a committee of the Conference of Soil Chemists of the National Agricultural Advisory Service.

Other publications include a report on the results of a survey (described last year) of progress under the Hill Farm and Livestock Rearing Acts, undertaken by officers of the Agricultural Land Service and the National Agricultural Advisory Service (195), a paper by Church on the use of weed-killers and insecticides (191), and a report by Church and Westmacott in collaboration with Dr. F. H. Jacob on the results of the 1954 survey of rabbit damage to winter cereals (194).

Colonial Work

Twelve Commonwealth workers have stayed in the Department for periods up to three months, and others have paid brief visits. Advice and assistance on the design and analysis of experiments and sample surveys has been continued. As already mentioned, Hodnett has now been appointed to the post of Statistician on a Regional Research Scheme based at the Imperial College of Tropical Agriculture, Trinidad and the future of this section is now under discussion with the Colonial Office. Hodnett completed his study of the responses of sugar-cane to fertilizers, and a general report is in the press (202).

Other Work

An investigation by Yates into the methods of analysis appropriate to a set of quantal experiments involving two treatments, which was substantially completed in 1954, was written up (213). A further note on a secondary point arising in the course of this investigation has also been prepared (214). The work on the electronic computer on the efficiency of the combination of probabilities test mentioned in the 1954 report originally arose out of this investigation. A report on this latter work is substantially complete, but pressure of other electronic work has delayed publication.

Healy has prepared notes on the test of significance for the difference in efficiency between two predictors (198), on weighted probits allowing for a non-zero response in the controls (200), on the prediction of adult body measurements from measurements taken in each year from birth to 5 years (in collaboration with others concerned in the Aberdeen Growth Study (211)) and on the chemical control of wireworms, with Potter and Raw (137).

Gower has prepared a note on a periodogram of the Beveridge Wheat Price Index arising from work carried out on the Manchester electronic computer (196).

Boyd and Lessells have prepared a note on the value of setting potato seed arising from their earlier work in this field (190).

Leech has contributed two papers on the subject of vital statistics in the study of cattle diseases (206, 207). He has also assisted in the elucidation of the sampling errors in observations on the behaviour of grazing cattle (210).

FIELD EXPERIMENTS SECTION

The following members of the staff, who constitute the Field Plots Committee, are responsible for planning and carrying out the programme of field experiments : F. Yates (Chairman,) H. V. Garner (Secretary), F. C. Bawden, H. H. Mann, J. R. Moffatt, R. K. Schofield, R. G. Warren and D. J. Watson.

Four Working Parties were constituted to prepare material for the Plot Committee : Classical and Long-Period Experiments (Chairman F. Yates), Pathology Experiments (Chairman F. C. Bawden), Agronomy Experiments (Chairman D. J. Watson) and Field Methods (Chairman R. G. Warren).

The number of plots comprised in the field experiments at Rothamsted and Woburn in 1955 were :

	Grain	Roots	Hay	Grazing	Total
Classical experiments					
Rothamsted	162	73	47	—	282
Woburn	15	—	—	—	15
Long-period experiments					
Rothamsted	532	384	209	96	1,221
Woburn	133	314	59	12	518
Annual experiments					
Rothamsted	563	181	48	—	792
Woburn	148	—	—	—	148
Total	1,553	952	363	108	2,976

Some of these plots were put down to provide material for observation only, but 2,781 were harvested and weighed. In addition, some 470 microplots were carried out at Rothamsted by members of the Chemistry Department, mainly on phosphatic fertilizers and fertilizer placement; and the Garden Plots Committee were responsible for about 360 microplots, mostly conducted by the Plant Pathology and Botany Departments. At Woburn H. H. Mann had twenty-five microplots for studies on exotic crops.

The weather as it affected agricultural operations is described in detail in the farm report; the following brief notes put on record the main features of 1955 to provide a general background for an account of the year's experimental work.

The general picture of the season 1955 was a very wet autumn, a severe and prolonged cold spell early in the new year, followed by one of the best summers for many years. In the period May to September inclusive there was a quite unusual succession of perfect summer days.

October opened dry and warm, ploughing was well forward, and on 15 October the first experimental wheat was drilled. Rain set in towards the end of the month and persisted all through November and most of December. The land soon became unworkable : Broadbalk was put in under very sticky conditions on 6 December, and a very small area of commercial wheat was sown on 28 December, leaving the bulk of the wheat and all the beans for spring sowing.

The last week of the year turned out dry with unusually high temperatures, but on 4 January a wintry spell set in which lasted for

all practical purposes till the middle of March. Very little productive field work could be done during this long period. Ploughing started again on 12 March, and sowing a week later in excellent frost tilths. April, with only $\frac{1}{2}$ inch of rain, was a month of almost uninterrupted field work, but May turned out wet and cold, with an exceptional blizzard on the night of 17 May. At this stage crops were backward owing to cold nights. June was a very dull month, with 50 hours less sunshine than average. The low evaporation kept the soil surface moist, and it was impossible to control the weeds in the root crops, particularly on Barnfield, while the early cut hay made only very slowly.

The warm, dry weather started towards the end of June and lasted with only slight interruptions for over 2 months. July had only $\frac{1}{4}$ inch of rain, and very effective horse-hoeing was carried out in the root crops. In the dry weather birds made an early start on the filling grain, but the new programme of crop protection reduced the damage to small proportions.

The dry weather continued in August, which only gave 0·85 inch of rain. There were no thunderstorms and practically no lodging. In spite of the good summer, ripening was not particularly rapid, and harvesting actually started on 4 August, and was nearly finished by the end of the month. By this time roots and potatoes were seriously affected by drought. It was not till 5 September that the long, fine spell was broken, but the rain was badly needed to soften the stubbles for ploughing, although it came too late for the potato crop. Further heavy rain fell on 22 September, but only stopped the ploughs for 1 day. With warm, bright days and $\frac{1}{2}$ inch of rain less than the average the month was a favourable one for farm operations. All cereal plots were in by 2 September, and the late-sown bean plots were combined by 12 September. Grass grew well after the long summer drought, and the sheep were put back on the grazing plots for the second half of the month. The first 18 days of October saw almost all the potatoes lifted in excellent condition, but there was then a week's rain that stopped all field work. The weather then improved with falling temperatures, and mangold lifting started on Barnfield at the end of the month. There was little rain in November, ploughing was well forward and by 24 November Barnfield was completed with the land in much better condition than usual at this time of year. The dry weather continued for the first half of December, all ploughing being completed by this time.

The Classical Experiments

Broadbalk

The main point of interest on Broadbalk is the re-establishment of a small section of the field in continuous wheat commencing with the crop of 1955–56. A full account of the bare-fallowing operations which broke the long series of wheat crops grown by Lawes and Gilbert is given in another contribution to this report. The land intended for continuous wheat lies at the West end of the field adjoining the Wilderness; it is part of Section I, which has carried 104 wheat crops since the beginning of the experiment, and has been fallowed 8 times since 1914. The last bare fallow on Section I was

in 1951, and it was therefore due to be fallowed once more in 1956; instead only the East half of Section I will continue in the fallowing cycle, leaving the West half to be drilled every year with wheat. At first it is proposed that the continuous section shall have the same cultivations as the rest of the field, but special cultivations or the use of herbicides may be considered if weeds become serious.

The wheat crop of 1955 was sown with difficulty on 6 December 1954, and the young plants had a long wintry spell from January till March. Nevertheless, all plots carried a good plant, and in the hot, dry summer which followed the field looked exceptionally well. There was practically no lodging and comparatively little trouble from eyespot (*Cercosporella herpotrichoides*); even Plot 8 with 6 cwt. of sulphate of ammonia per acre was harvested without difficulty —a most unusual occurrence. Wild oats were hand-pulled as usual but, thanks to systematic pulling in the past, this weed is now well under control. Bird damage, which in some years has been quite serious on Broadbalk, was unusually light this summer, partly owing to the stringing of the danger spots. The damage on the worst areas near the Wilderness and cottages was estimated at only 2 per cent.

Hoosfield

The first chalking under the new system was completed in hard weather in mid-March, and the barley was drilled in a very good frost tilth on 7 April. Heavy rains in May damaged the surface tilth, especially on Strip 3, which, being slightly hollow in the centre, held much water and was very badly capped. On 24 May the routine spraying with DNOC was carried out. It was only possible to hand-pull wild oats for 4 days at the end of July, and this was insufficient to clear the whole area completely, consequently a reduced area was picked clean for harvest on certain plots, the remainder of the produce being cut and carted green. The liming of the acid areas of this field, although only carried out a month before drilling, certainly improved the crop; Plot 5A in particular, which has grown practically no barley for several years, produced almost a normal crop after liming. In the summer drought the straw was very short except on the dung plot, where a little lodging occurred. Some of the poorer plots in the no-phosphate series were too short for the binder and were cut by mower.

Barnfield

Mangolds and sugar beet were sown on 23 April in a fairly good seedbed. Growth was slow in the cold weather which followed, and singling did not start till 23 June. By that time there was an extraordinary growth of annual weed, and wet weather very seriously hindered inter-row cultivations, so much so that the plants on the worst-affected plot (4AC) were cultivated out, leaving only 4 rows to stand for yield. Growth on all plots was poor during the summer drought, though the usual treatment differences appeared on a reduced scale, and when the dry weather broke in September it was clearly too late and yields turned out very light.

Owing to the alarming spread of " twitch " (*Agropyrum repens*) along the dung plots and across the no-nitrogen series, it was decided to make a test of TCA (sodium trichloracetate) against this

weed. Consequently one-half of each plot that was badly affected was sprayed on 9 April at 20 lb./acre in 80 gal., leaving the other half unsprayed. Although the roots were drilled only a fortnight afterwards, no harm resulted, but the twitch was reduced to a very satisfactory degree on the treated areas, though it showed some signs of recovery at lifting time. This procedure will be trested again.

Plot 8N, sodium nitrate only, started with a good plant, but this gradually failed during the growing season. At lifting time many of the plants were small and carried a tuft of dead leaves, some plants being completely dead. Magnesium deficiency was suspected, and crop samples are being examined in the laboratory.

Park Grass

The showery weather in May followed by the cool weather in June was on the whole favourable for hay production. Some of the acid plots which normally show bare patches in a droughty spring were colonized by seedling Yorkshire Fog, which contributed appreciably to the yield, and the crop turned out well above average. Cutting began on 29 June under ideal conditions, and the hay was baled and weighed within a week. The second cut, taken on 16 September following the long, dry summer, was very light indeed.

Agdell

This field was drilled with spring wheat with a basal dressing of nitrogen. The crop was rather more uniform than the previous two barley crops, but still showed marked variations within the old treatments, partly but not entirely due to irregular distribution of take-all disease. The wheat was not weighed by plots, but just before harvest soil and crop samples were taken from good and bad areas for chemical examination and assessment of take-all.

Exhaustion Land

The first dressing of ground chalk was given in December 1954 and the remainder in March 1955. On Plot 2 (unmanured), which was originally very acid, the chalk produced a marked improvement. There was a good plant everywhere, and the residual effect of the early dung applications was unusually striking all through the growing season. Weeds are now giving some trouble locally on this experiment : part of Plot 2 was infested with twitch (*Agrostis alba*) and had to be rejected at harvest, and mayweed (*Matricaria inodora*) was very plentiful in Plot 6 (nitrogen only).

Long-period Experiments

The four-course rotation has now been recast to measure the effect of small annual dressings of superphosphate as affected by the residuals of the original organic treatments. This is done at two levels of nitrogenous manuring on each crop of the new rotation : potatoes, barley, beans, wheat, in which beans take the place of ryegrass. During the growing season there were visible residual effects of bulky organic manures in the cereal crops, though the most striking effect was that due to the direct application of nitrogenous

fertilizers. Potatoes cropped badly owing to the drought and turned yellow very early in the season. Beans started well, but they were attacked by aphis late in the season and gave a poor and rather variable crop.

The six-course rotation testing deep cultivation has completed two whole rotations on the earliest blocks, and these have now been discontinued; the remaining blocks will also terminate as they complete their cycles. The cereals and hay were very good this year, and showed visible improvement from the farmyard manure applied to roots earlier in the rotation. Potatoes and sugar beet were both rather light crops, showing considerable benefit from dung, which kept the potatoes in active growth when those without dung were dead; potash had a similar effect. Deep ploughing appeared to benefit the sugar beet.

The ley–arable rotation, now in its seventh year, has been slightly modified in the light of further experience. It was found that the barley test crop invariably lodged on Highfield, where fertility is still high after the old grass; consequently Plumage Archer has now been replaced by Proctor and the levels of nitrogen on test have been reduced by 0·2 cwt. N. As mentioned in the last report, eyespot disease (*Cercosporella herpotrichoides*) was increasing to dangerous levels in the wheat and barley of the entirely arable rotations, especially on Fosters. To reduce this trouble the barley in the treatment phase has been replaced by oats. In view of the widely different amounts of potash withdrawn by the various treatment crops, cut grass, for example, removing much more than grazed ley, it was decided to introduce a test of potash in the following potato crop to measure differential effects due to previous cropping. To complete the information a similar test of phosphate was introduced also. A system of compensating dressings to take account of the differential withdrawals of potash is being worked out and put into operation. The first year's results of these additional treatments are given in Table 1, which also contains the effects of the leys on the three test crops.

Highfield, still showing after 7 years the benefit of the old turf, was more productive in all crops than Fosters, and at this stage rotations based on leys had no particular advantage over purely arable cropping. Dung showed up well on potatoes on both fields, but was less necessary after grazed ley. Increasing the potash from 0·9 to 1·8 cwt. K_2O gave better results after cut lucerne and cut grass than after grazed ley or arable cropping.

The grasses and leys of 1955 started the season well. Grazing began on 27 April and continued for 3 months, holding out well against the increasing drought. On 27 July, however, the sheep had to be removed for nearly 2 months, when rain then brought on a second flush and grazing was resumed till the middle of October. The first-year ley was fairly good on Highfield but very poor and weedy on Fosters; aftermath grass on the hayed plots was rather small. The output of dry matter from the permanent grasses and the rotation leys is given in Table 2.

In this droughty summer the permanent reseeded grasses on Fosters were more productive than the grazing leys. The outstanding success was lucerne, for although the first year's crops were below expectation, established lucerne in its second and third season

Table 1

Yield of test crops, 1955

	After 3 years' cropping with :				
	Lucerne	Grazed ley	Cut grass	Arable crops	Mean
First test crop :					
Wheat, grain, cwt./acre					
Highfield	48·0	48·9	38·9	47·9	45·9
Effect of 0·3 cwt. N ...	5·6	0·0	1·6	0·9	2·0
Fosters	38·2	34·8	34·6	32·9	35·1
Effect of 0·3 cwt. N ...	3·8	3·5	−0·6	4·6	2·8
Second test crop :					
Potatoes, tons/acre					
Highfield	10·05	10·48	9·78	10·53	10·21
Effect of 12 tons dung ...	2·58	0·77	1·81	1·58	1·68
Effect of 0·5 cwt. N ...	1·10	0·59	0·00	0·50	0·54
Effect of 0·9 cwt. P_2O_5 ...	0·56	−0·11	0·13	0·26	0·20
Effect of 0·9 cwt. K_2O ...	1·34	1·07	1·67	0·82	1·22
Fosters	8·62	8·29	7·35	7·65	7·97
Effect of 12 tons dung ...	1·61	0·63	2·26	0·77	1·31
Effect of 0·5 cwt. N ...	−0·23	0·31	−0·59	0·13	−0·09
Effect of 0·9 cwt. P_2O_5 ...	0·45	0·49	0·54	0·12	0·39
Effect of 0·9 cwt. K_2O ...	0·65	0·34	0·95	0·25	0·55
Third test crop :					
Barley, grain, cwt./acre					
Highfield	50·6	48·6	48·6	49·0	49·2
Effect of 0·2 cwt. N * ...	1·8	0·2	−4·0	4·4	0·6
Fosters	48·4	46·5	45·1	45·5	46·4
Effect of 0·2 cwt. N ...	2·2	4·0	3·1	1·7	2·8

Note : The fertilizer effects are the increases of the double dose of nutrients above the single dose; i.e., the effect of 0·5 cwt. N to potatoes is 1·0 cwt. N–0·5 cwt. N.

* No single dose of nitrogen n this case.

Table 2

Rothamsted ley–arable experiment, Highfield and Fosters, 1955

Yield of dry matter, cwt./acre

	Old grass		Reseeded grass		3-year ley	Cut grass	Cut lucerne	1-year ley hay
	Hay	Grazing	Hay	Grazing	Grazing			
				Highfield				
Blocks :								
First year ...	—	34·3	—	33·3	27·1	34·1	24·5	49·7
Second year ...	—	40·9	—	51·9	57·0	53·7	109·8	—
Third year—								
Blocks 6 and 7	55·9	25·2*	65·0	30·1*	61·2	39·0	79·6	—
Blocks 5 and 8	—	35·3	—	42·1	—	—	—	—
				Fosters				
Blocks :								
First year ...	—	—	—	33·5	10·4	10·5	23·3	54·2
Second year ...	—	—	—	39·5	37·6	40·2	111·9	—
Third year—								
Blocks 8 and 9	—	—	67·6	19·6*	41·5	34·2	106·9	—
Blocks 5 and 7	—	—	—	28·4	—	—	—	—

* Aftermath grazing.

averaged well over 5 tons of dry matter per acre. The season was unfavourable for cut grass, although extra nitrogen greatly improved the level of yield. The undersown 1-year ley yielded less than usual, but nevertheless produced far more than any spring-sown ley in the first year.

Annual and Short-period Experiments

These experiments fall into two classes, depending on whether the main interest is in plant nutrition or plant disease. Many of them are carried out by or on behalf of the scientific departments who undertake the necessary sampling and observations.

Fertilizer experiments

(1) Spring wheat, Sawyers I. Residues of dung and fertilizers applied to the potato crop of 1954. This experiment again showed higher wheat yields on the plots that received sulphate of ammonia for the potato crop.

(2) Spring wheat, Great Field I. Seedbed applications compared with early and late top dressings of " Nitro-Chalk " at three rates and in all combinations. The field was in such high fertility that all nitrogen effects were small. There was no lodging.

(3) Spring wheat, Great Field I. Varieties and two levels of nitrogen. The experiment showed clear differences between varieties but no advantage this season for high levels of nitrogen.

(4) Barley, Great Field I. Seed rates and levels of nitrogen applied in the seedbed. With a very heavy crop the yield effects were small and non-significant. Heavy seed rates combined with high levels of nitrogenous manuring produced lodging. Records of incidence of eyespot and take-all were made by the Plant Pathology Department.

(5) Barley, Great Field I. Seedbed applications compared with early and late top dressings of " Nitro-Chalk ", at three rates and in all combinations.

(6) Barley, Great Field I. Varieties and nitrogen. The newer varieties, Herta and Proctor, were compared with Plumage Archer, with and without nitrogen. Intensive plant observations were made during the growing period by the Botanical Department.

(7) Barley, Great Field I. Varieties and nitrogen. Plumage Archer was out-yielded by each of the seven modern varieties with which it was compared. High nitrogen dressings were harmful this season.

(8) Barley, Highfield V. Residual effects of phosphate and potash applied to lucerne in 1952. A heavy crop of barley which showed a small residual effect of potash.

(9) Spring beans, Fosters Field. Control of weeds by spraying with DNBP and by cultivations.

(10) Lucerne, Great Harpenden II, first year. Levels of potash given either all in the first year or distributed equally over 3 years.

Placement experiments (G. W. Cooke, Chemistry Department)

(1) Potatoes, Little Hoos. Three levels of nitrogen and of potash, broadcast or placed in a side band, in all combinations.
(2) Kale, Great Harpenden II. Combinations of nitrogen, phosphate and potash, broadcast or placed near the seed.

Experiments on soil structure (W. W. Emerson, Physics Department)

(1) Fosters Field. Effect of 5 years under various leys measured in spring beans followed by wheat.
(2) Long Hoos I. First preparatory year of new experiment. Ryegrass ley, cocksfoot ley and bare fallow have been established.

Experiment on wild oats (J. M. Thurston, Botany Department)

(1) Survival of wild oats under ley, Great Knott I, first year. Ley established in spring 1955 in oat-infested land and some plots ploughed up in autumn 1955 to test effect of one summer under grass. Further plots will be ploughed up yearly.

Plant pathology experiments

(1) Eyespot rotation, Long Hoos II and III, second preliminary year (M. D. Glynne, Plant Pathology Department). Winter wheat, two varieties, two seed rates, two levels of nitrogenous top dressing. Grown after wheat or after potatoes.
(2) Winter wheat, Long Hoos VII, second preliminary year (D. B. Long, Entomology Department). Effect of plant density on incidence of wheat bulb fly. Four different degrees of ground cover were obtained in 1954 and again factorially with the first year, in 1955.
(3) Winter wheat, Pennell's Piece, first year (M. J. Way, Insecticides Department). Test of four insecticidal treatments on wheat bulb fly.
(4) Spring beans, Fosters Field (M. J. Way, Insecticides Department). Test of spraying against aphids in relation to four times of sowing the seed.
(5) Potatoes, Little Hoos (L. Broadbent, Plant Pathology Department). Effect of spraying against aphids on spread of leaf roll and virus Y. Plots sprayed with DDT emulsion 0, 2, 4, 6, 8 times during the summer.
(6) Potatoes, Stackyard Field (J. M. Hirst, Plant Pathology Department). Effect of copper fungicide on late blight (*Phytophthora infestans*).
(7) Potatoes, Little Knott (J. M. Hirst, Plant Pathology Department). Effect of copper fungicide and of burning off haulm with sulphuric acid on late blight.
(8) Broccoli, Great Knott I (L. Broadbent, Plant Pathology Department). Effect of dung and levels of nitrogen on spread of cauliflower mosaic virus.

The results of the experiments carried out for workers in the scientific departments are usually reported by the departments concerned.

Broadbalk Fallow

Under the original scheme of continuous winter wheat weeds were always a serious problem. In Lawes's and Gilbert's time much hand labour was expended on keeping the plots clean, but in wet years this was quite ineffective. Various methods of reducing the weeds were tried. In 1889 half the field was drilled in 16-inch rows to allow thorough inter-row cultivation; in the following year the other half was similarly treated. In 1904 each strip was divided lengthways into halves so that one-half of each plot could be bare fallowed, the remainder was fallowed in 1905. For the next 20 years the wheat was grown on 12-inch rows to facilitate hoeing. In 1914 the whole of the western half, i.e., nearest the farm buildings, was bare fallowed, and in 1915 the whole of the eastern half. The field was then cropped in the normal way till the harvest of 1925, when it was divided transversely into five equal sections in preparation for a regular cycle of crops and bare fallows. In 1926 and 1927 the three western Sections, 1, 2, 3, were fallowed, and in 1928 and 1929 the three eastern Sections, 3, 4, 5. Section 3 therefore received four consecutive bare fallows. In 1930 the whole field was drilled with wheat, and in the following years a sequence of 4 years wheat and 1 year bare fallow was built up on each section in turn, so that by 1935 the experiment was in full cycle, each section carrying one phase of the sequence: bare fallow, first, second, third and fourth wheat crops after fallow. The actual operations of bare fallowing vary from year to year according to the weather, but they usually conform fairly closely to the following scheme: The first operations on the plots due to be fallowed are the same as on plots being prepared for wheat, i.e., a single ploughing in September followed by from one to three strokes with the spring-tine cultivator about a month later. A second ploughing follows on a favourable occasion between December and March, and frequently a third between June and August. Each ploughing is followed by one or more strokes with the spring-tine cultivator to disturb successive crops of seedlings, and from May to July the thistle bar is used as necessary to cut strong perennial weeds. The fallow section is once more ploughed with the rest of the field for the next wheat crop.

Four complete 5-year cycles are now available covering the period 1935–54, and in Table 3 the average yields of grain and straw are given for each treatment, as well as the long-term average over the period 1852–1925, when the field was in continuous wheat. The figures for the final 10-year period under continuous wheat are also included.

The broad result of the fallowing of Broadbalk has been greatly to raise the productivity of all plots, particularly in the year immediately after the fallow. This may be seen in the last line of the table. The mean yield of all the plots has been increased by 3·1 cwt. grain and 9·3 cwt. straw above the long-term yield when under continuous wheat. The effect is no less than 6·7 cwt. of grain and 14·5 cwt. of straw when compared with the average production of the last 10 years before fallowing started. Fallowing has a big effect on the first year's crop and an appreciable one on the second year's crop, but the residual effects in the last two crops are small. Thus, taking the yield in the fourth year after fallow as the point of

TABLE 3

Effect of fallowing, Broadbalk Field, 1935–54

Means of four complete cycles

Plot		Years after fallow: 1st	2nd	3rd	4th	Mean	Means 1852–1925	Means 1916–25	Years after fallow: 1st	2nd	3rd	4th	Mean	Means 1852–1925	Means 1916–25
		Grain, cwt./acre							Straw, cwt./acre						
2A	D	25·1	20·0	19·3	16·9	20·3	16·3 *	13·8	55·7	44·2	41·5	40·7	45·5	32·1 *	25·5
2B	D	25·7	22·6	21·2	19·1	22·2	19·4	15·5	57·8	48·4	45·6	45·4	49·3	34·2	30·1
3	O	16·1	9·0	8·7	8·7	10·6	6·7	4·8	28·1	15·1	14·6	14·7	18·1	9·8	6·6
5	C	19·0	10·3	9·5	10·3	12·3	7·8	5·2	34·2	19·1	17·8	20·1	22·8	11·5	7·4
6	N_1C	22·0	13·9	12·3	12·9	15·3	12·5	8·7	42·1	26·7	24·5	26·9	30·0	20·3	13·9
7	N_2C	24·1	18·8	17·1	17·3	19·3	17·6	14·0	49·4	39·5	35·3	36·4	40·2	32·1	26·1
8	N_3C	24·8	22·1	20·0	20·0	21·7	20·1	15·3	54·3	50·9	47·4	47·4	50·0	39·8	33·3
9	$N_1'C$	21·7	15·7	14·1	14·9	16·6	13·9 †	11·2	42·4	30·8	27·9	29·3	32·6	24·6 †	20·5
10	N_2	17·2	18·6	15·0	14·4	16·3	10·9	8·0	33·2	32·5	27·0	26·3	29·8	17·8	14·9
11	N_2P	17·1	16·8	14·9	14·1	15·7	12·3	7·7	34·0	31·2	27·5	27·1	30·0	21·4	17·7
12	N_2PS	20·3	18·5	16·6	16·4	18·0	15·7	10·2	39·3	34·8	30·4	30·6	33·8	26·8	20·8
13	N_2PK	24·3	18·0	16·0	16·4	18·7	17·0	12·9	48·6	37·7	32·7	33·8	38·2	30·6	25·6
14	N_2PM	21·5	18·7	16·9	16·3	18·4	15·5	10·6	41·9	36·1	30·9	31·2	35·0	26·8	21·5
15	$(N_2)C$	23·3	16·1	15·1	15·7	17·6	16·1	11·1	44·6	31·4	28·9	31·1	34·0	28·2	20·9
16	$N_2'C$	25·1	21·2	19·6	19·5	21·4	17·8 †	14·8	52·1	42·9	40·8	40·3	44·0	35·2 †	30·3
17 & 18	N_2	22·8	17·7	17·5	18·1	19·0	16·1	11·7	43·8	33·4	33·6	33·8	36·2	28·1	20·9
17 & 18	C	18·8	9·3	7·6	7·5	10·8	8·1	6·2	34·5	16·8	13·9	14·6	20·0	12·3	8·4
19	R	22·6	17·4	14·9	15·5	17·6	12·6 ‡	8·3	42·0	31·5	27·0	28·3	32·2	22·0 ‡	15·2
	Mean :	21·8	16·9	15·4	15·2	17·3	14·2	10·6	43·2	33·5	30·4	31·0	34·5	25·2	20·0

Notes: Manures per acre applied to every wheat crop, but not in the years of bare fallow:—D farmyard manure, 14 tons (2A since 1885, 2B since 1843); O unmanured; C superphosphate, 65 lb. P_2O_5 (P), sulphate of potash, 98 lb. K_2O (K), sulphate of soda, 100 lb., sulphate of magnesia, 100 lb.; N_1, N_2, N_3 sulphate of ammonia, 43 lb., 86 lb. and 129 lb. N; N_1', N_2' nitrate of soda, 43 lb. and 86 lb. N; S sulphate of soda, 366 lb.; M sulphate of magnesia, 280 lb.; (N_2) sulphate of ammonia, 86 lb. N in autumn; R castor bean meal, 1889 lb.

* 1900–25. † 1885–1925. ‡ 1893–1925.

reference, there is a mean effect of 6·6 cwt. grain per acre in the first year, a residual effect of 1·7 cwt. in the second year but of only 0·2 cwt. in the third.

The results for the individual manurial treatments show differences. The three treatments with the lowest mean yields 3, 5, 17–18C, all no-nitrogen plots, give the greatest first-year response to bare fallowing: an increase of 9·1 cwt. grain and 15·5 cwt. straw per acre, the crop being practically doubled. Fallowing, however, is beneficial even to the best treatments; thus the three plots in highest fertility, 2B, 8, 16 are improved in the first year by 5·7 cwt. grain and 10·3 cwt. straw. A series of plots all having PK but with increasing levels of nitrogen show that the immediate effect of fallow declines as the direct addition of nitrogen increases.

		First-year fallow effect (cwt.)	
Plot number	N lb./acre	Grain	Straw
5, 17–18C	0	10·0	17·0
6, 9	43	8·0	14·2
7, 13	86	7·4	13·9
8	129	4·8	6·9

These facts suggest that the effect of fallowing is, at any rate in part, an addition to the available nitrogen in the soil.

The treatments may be divided into four groups differing slightly in their responses to the fallow.

TABLE 4

Mean yield, cwt./acre, and (in brackets) as per cent of mean yield

		Grain				
Treatment	Plot numbers	1st year	2nd year	3rd year	4th year	Mean
Farmyard manure	2A, 2B	25·4 (119)	21·3 (110)	20·2 (96)	18·0 (85)	21·2
Complete fertilizer 86 lb. N	7, 13, 15, 16, (17–18)N_3	23·9 (124)	18·4 (96)	17·2 (89)	17·4 (91)	19·2
No nitrogen	3, 5, (17–18)C	18·0 (161)	9·5 (85)	8·6 (77)	8·8 (78)	11·2
No potash, soda or magnesia	10, 11	17·2 (107)	17·7 (111)	15·0 (94)	14·2 (89)	16·2

The two high-yielding series given by dung and complete fertilizer respectively differ in the last year of the fallow cycle, for the yields with fertilizer practically reach their lowest level in the third year, whereas the dunged plots show a further marked decline in the fourth year. The poorest crops are those without nitrogen; in this series the fallow effect of +9·2 cwt. or 83 per cent of the mean yield in the first year is outstanding, both actually and relatively. The two treatments without potash are unusual in that the yield in the first season is no better than that in the second.

Effect of fallow on weed population

The effect of the Broadbalk fallowing operations on the weed population has been studied in the Botany Department in two ways: (1) by identifying and counting the number of seedlings of annuals produced in surface soil samples when kept for 3 years in good conditions for germination; (2) by estimates made in the field. Much of the data have already been published, and the work still continues. The following notes do no more than illustrate a few of the results obtained.

Of the annual weeds, poppy (*Papaver rhoeas*) and slender foxtail (*Alopecurus agrestis*) were the most conspicuous under continuous wheat. Fallowing affected them quite differently. Poppy was only

slowly reduced, but failed to re-establish itself; slender foxtail was greatly reduced in the year of fallow, but quickly built up again. The enormous population of weed seeds and the effect of the fallowing system at each stage in the cycle is seen in Table 5.

TABLE 5

Reduction in weed seed population by periodic bare fallowing, Broadbalk, 1930–40

Mean of plots 2, 7, 18

Relative numbers, year before fallow = 100

	Year before fallow							
	Actual per sq. foot	Per cent	Year of fallow	Years after fallow 1st	2nd	3rd	4th	Year of next fallow
All annuals ...	2960	100	49	69	77	85	81	35
Alopecurus ...	645	100	19	89	125	132	131	19
Papaver ...	800	100	67	56	49	49	55	33

Comparing the populations in 1925, the last year of continuous wheat, with those found 20 years later, the species may be classified as follows :

Changes in weed population due to fallowing, 1925–45

Soil sample data

Species showing reduction of: 85–90%	Over 75%	Over 60%	Species showing little change	Species showing increase
Papaver rhoeas	*Aethusa cynapium*	*Scandix pecten-veneris*	*Alopecurus agrestis* *	*Medicago lupulina*
Atriplex patula	*Galium aparine*		*Bartsia odontites*	*Stellaria media*
Caucalis arvensis	*Myosotis arvensis*		*Capsella bursa-pastoris*	
Polygonum aviculare	*Veronica arvensis*		*Veronica hederaefolia*	

* But very big reduction in first year.

The field observations were in general agreement with the above. In addition, they revealed an increase of *Vicia sativa, Matricaria inodora* and *Ranunculus arvensis* since fallowing was introduced. The field observations covered the perennials also, chiefly *Convolvulus arvensis, Cirsium arvense, Tussilago farfara* and *Sonchus arvensis.* The intensive fallowing of the period 1926–29 materially reduced these species, *Sonchus* being practically eliminated. *Convolvulus* and *Cirsium* are probably increasing again under the rotational fallow system.

With 1 year's fallow in 5 Broadbalk is much cleaner than it used to be, the heavier and denser crops of wheat that are now grown probably helping to reduce weeds.

Wild oats, *Avena ludoviciana,* were frequent on Broadbalk by 1931, and became serious during the Second World War. Bare fallowing every 5 years has very little effect on this weed, but systematic hand-pulling, begun in 1945, has almost eliminated it.

Effect of bare fallow on eyespot and take-all

Every year the incidence of eyespot, *Cercosporella herpotrichoides,* is lower in the section following bare fallow than in the sections after crop. Observations made on eight plots over the 18-year period, 1938–55, show that the deep lesions on the straw which cause serious loss of yield are reduced from 45 per cent on wheat after wheat to 21 per cent on wheat after fallow.

Take-all, *Ophiobolus graminis*, is common on plots which received no nitrogenous fertilizer. The disease is severe enough to cause loss in yield in some years in sections after crop, but is generally absent or relatively slight after fallow. One of the ways in which the fallow has increased the yield of the less-fertile plots is by control of take-all.

Wheat bulb fly

The sequence of wheat crops and bare fallows on Broadbalk provides suitable conditions for the establishment of a permanent infestation of wheat bulb fly (*Leptohylemyia coarctata* Fall.). From 1930 onwards damage from this pest was noted, mainly on the crop immediately after bare fallow. In most years the plant, although thinned in the winter and early spring, filled up again and the effect on yield was judged to be slight. In a few seasons the loss of plant was so great that there could be no doubt that yields were affected. Thus in 1936 the mean yield of the whole section after bare fallow was less than that of the neighbouring section carrying the second crop after fallow, and less than that of another adjoining section carrying the fourth crop after bare fallow. Other bad years were 1950 and 1953. When the plant is seriously thinned by wheat bulb fly, weeds quickly come in, and the crops after fallow may be much more weedy than the rest.

Counts of larvae on the wheats after fallow show that the population varies widely from year to year. There is not yet sufficient evidence to judge how far the different manurial treatments effect egg laying and the subsequent larval infestation.

Staff

C. R. L. Scowen transferred from the Farm Staff to replace Kathleen Ogborn who left the Section to go to the Aden Protectorate. Mr. J. L. Hammerton, Department of Agriculture, Reading University, spent the long vacation on the farm assisting in the work of the Section. H. V. Garner spent three weeks in Holland, West Germany and Denmark studying field experimental methods, and also attended the meeting of the International Institute of Sugar Beet Research at Brussels.

THE FARMS

J. R. Moffatt

Rothamsted

The year 1955 started badly because the extremely wet autumn and early winter of 1954 seriously delayed all field operations, including the drilling of winter corn and beans. All land work was therefore seriously behind schedule at the beginning of the year. Spring operations started later than usual, but a dry spell in April enabled the full programme of work to be carried out. The hot, dry summer was very favourable to corn crops, but root crops suffered severely from the lack of rain. The autumn was very favourable to land work, and the harvesting of the root crops and the drilling of winter corn was completed without difficulty.

The Effect of Weather on Crops

Owing to the extremely wet weather conditions in the late autumn and early winter of 1954, very little winter ploughing had been done by the end of the year. Most of the small experimental areas of winter corn were drilled in October 1954, but the bulk of the corn drilling could not be done until December. The acreage sown to winter corn was lower than had been planned, and it was not possible to sow any winter beans.

The early months of 1955 did not bring any marked improvement in conditions, and only very little land work was possible during January, February or early March. By this time work was seriously behind schedule, but a fine spell in the latter half of March enabled spring land work to start in earnest. After a changeable start, April produced a long spell of fine, dry weather, and excellent progress was made with seedbed preparations and the sowing of crops. However, frequent night frosts and cold winds retarded germination and growth of all crops.

Weather during May and June was generally cold, wet and changeable, which seriously hampered farm work, further retarded growth and made weed control difficult. Conditions improved in the latter half of June, and throughout July, August and September we had hot and dry weather. All corn crops made good growth during this period, and conditions were good for both hay and corn harvests. However, the growth of all root crops was seriously affected.

The fine spell continued into October, and, while the lifting of the potato crops was facilitated, the autumn ploughing was delayed somewhat by the hard state of the ground. Rain later in the month enabled nice seedbeds for winter corn to be obtained, and drilling was completed in good time.

After a changeable start in November, more settled, dry conditions prevailed in the latter half of the month, and the lifting of mangolds and sugar beet was completed under good conditions. Mild, open weather continued until the end of the year.

Field Experiments

A very full programme of field experiments was carried out during the year. Except for delaying the start of spring work, weather conditions were very favourable to field work, and no insuperable difficulties were met. Yields of cereals were generally very satisfactory, but there was a disappointingly small response to nitrogen, and root-crop yields were low. Operations on experimental plots were mechanized as far as possible, and this year some of the long-term rotation experiments were combine-harvested for the first time. It is hoped that within a year or two even the Classical corn fields will be harvested in this manner. The experiments embraced most of the common farm crops, and an account of them is given in the report of the Field Plots Committee.

Cropping and Rotations

Of the 442 acres farmed, 368 were under arable crops, of which 237 were under tillage. The main tillage crops were wheat 70 acres, barley 82 acres, oats 9 acres, beans 15 acres, potatoes 27 acres, and kale, mangolds and sugar beet 19 acres.

The reservation of about eleven fields as sites deficient in phosphate or potash, the limitation of the potato acreage which can be grown as a cleaning crop and the necessity to provide sites for cereal experiments on land not having grown cereals for a number of years have resulted in a revision of the cropping programme. The acreage of wheat and barley was reduced by 20 acres, and the area under beans was slightly increased. A further increase in the bean acreage is planned for 1956, and the acreage under oats will be increased. On the reserved sites which are low in phosphate or potash, where it is useless to sow the normal cleaning crop of potatoes, bare fallowing may be used, though this is a retrograde step, and the use of short-term leys will be extended. Both these methods of cleaning reserved sites have already been put into effect.

Use of Sprays

A very full programme of spraying was carried out during the year, with very satisfactory results. Most of the cereal crops were sprayed with MCPA or DNOC, the latter spray being used mainly against cleavers (*Galium aparine*).

Several areas of land infested with couch grass (*Agropyrum repens*) were sprayed with TCA, and this resulted in a satisfactory reduction in the amount of couch grass present. Half of several plots in Barnfield, where mangolds are grown continuously, were sprayed as late as 9 April, and while the effect on the couch was satisfactory, there was no effect on the germination or growth of mangolds and sugar beet planted 2 weeks later.

The mangolds and sugar beet were severely attacked by the mangold fly (*Pegomyia betae*) when in a young stage, and all crops were sprayed with miscible DDT. This was effective in preventing further damage.

No spraying was needed this year against the flea beetle, nor were the beans sprayed, as the early infestation by bean aphis did not appear severe.

Crops

Wheat

Very little winter-sown wheat was grown because of adverse conditions in the autumn. A few acres of Heine's VII, though sown in late December at a low seed rate, produced an extremely good level piece of wheat which yielded 40 cwt./acre. The Squareheads Master 13/4 grown on Broadbalk looked well throughout the year, and no lodging occurred. Small areas of Cappelle, Yeoman and Holdfast were also grown.

Koga II spring wheat was grown for the second year, and again gave an excellent yield on experimental plots and non-experimental areas. Yields of over 40 cwt./acre were obtained. Atle wheat was also grown, but was outyielded by the Koga II, which variety has now been accepted as the standard variety of spring wheat. All wheat crops stood perfectly.

Despite the double pulling of wild oats on Broadbalk field for several years, the field is still not clear of this weed. This hand-pulling must remain a standard practice, otherwise a rapid build-up is likely to occur.

Barley

Both Herta and Proctor were grown, and both varieties gave good crops, both as regards yield and quality of grain. No lodging took place, and the crops were easily dealt with at harvest-time.

Plumage Archer is still retained on experimental areas where continuity is required. On the Hoosfield Classical barley plots wild oats were again very numerous. As much hand-pulling as was possible was done, but the infestation was so heavy that large areas of many of the plots had to be cut green and carted off before the oat seed shed. Yield figures for these plots were taken from small areas from which the weeds had been pulled.

Oats

The variety Sun II was grown, and a good crop of approximately 27 cwt./acre was obtained. This was the only non-experimental crop to be cut by binder.

Beans

No winter beans were sown, but an increased acreage of spring beans were drilled by Smythe drill. Early growth was slow, but later the crop grew rapidly and promised a heavy yield. The cold weather in May and early June delayed flowering, while the very hot, dry weather in July brought flowering to a premature end. In addition, a late infestation of black fly (*Aphis fabae*) occurred when the crop was too far forward to permit spraying, and severe though localized damage occurred.

It was decided to try to harvest the crop by combine-harvester, and the most satisfactory method for a fairly ripe crop was to cut when the crop was damp and with the reel removed. Using this method losses appeared to be smaller than if a binder had been used.

Potatoes

The acreage of this crop was kept fairly low because difficulty was expected in obtaining suitable labour for lifting. The cold weather

in early summer retarded growth, and later in the season the very hot, dry weather had the same effect. The crop remained backward throughout the growing period, and this poor growth is reflected in the yields, which were about half the normal. No spraying against late blight (*Phytophthora infestans*) was done except for experimental purposes, and no appreciable amount of disease developed. A small area of King Edward VII were grown, and these appeared less seriously affected by drought than the Majestics, and had considerably less scab. Local labour was available this year for picking, and this operation finished earlier than usual.

Sugar beet and mangolds

The area devoted to these crops was kept to a minimum owing to their heavy labour demands. After a slow start both crops were damaged by the mangold fly (*Pegomyia betae*) at an early stage, and they then suffered severely from the drought. Individual plants and total yield were small, and the sugar content of the beet was disappointingly low.

Kale

Three small separate areas were devoted to this crop, and on all three the plants lacked vigour and looked very parched and backward during the whole season. No trouble from flea beetle was encountered as the seed was treated with BHC.

Grassland

Growth of grass in the early part of the season was very slow, even where a nitrogenous top dressing was applied. It was not until well into May that real growth started. However, the cattle and sheep had just sufficient keep without having to open up any of the fields reserved for hay. Keep was adequate during the early summer months, but tended to fall off owing to the drought in August and September. Late autumn grass made some growth, and most of the stock remained out until well into December.

Haymaking was delayed until late June and early July because of slow growth and unsettled weather, but the crop was eventually secured in excellent condition.

Livestock

Cattle

In view of the high beef prices during the winter of 1954–55, the bigger cattle were pushed on as rapidly as possible in the yards, and 13 were sold during first 4 months of 1955.

The younger North Devon cattle purchased in the late autumn of 1954 were yarded during the winter and were fattened on the grass during the summer of 1955. In view of the shortage of grass we were fortunate not to have too many to fatten off.

During the year 44 cattle were sold fat, and 93 store cattle, mainly crossbred Herefords, were purchased. The smaller cattle were yarded early in the winter of 1955, but some of the larger ones were still grazing out at the end of the year. 52 of the cattle are in a temporary open yard adjoining some large stacks of old straw which they will tread into farmyard manure. They are being fed

fairly liberally with a ration of home-grown feeding-stuffs with a view to having them fit for slaughter early in the summer. Hay, and oat straw *ad lib.* are being fed. It is hoped in this way to utilize profitably our rather large stocks of hay, straw and grain seconds.

Sheep

The small flock of Scotch Half-bred ewes was retained and was mated to Suffolk rams to produce tegs for grazing the experimental field plots.

From the 76 ewes put to the rams in 1954, 102 lambs were tailed. Some of these have been sold fat, the remainder are being retained.

Implements

Following upon the very successful experience in 1954 with a 10-foot self-propelled combine, both on experimental field plots and non-experimental areas, a second such machine was purchased in 1955. This enabled us to harvest in this way a far bigger proportion of plots than ever before, and again the technique used proved very satisfactory. The second machine, besides enabling one machine to be used for full-time work on experimental plots, speeded up work on non-experimental areas, and was always in reserve in case of mechanical breakdown of the machine on plot work.

Further progress was made towards standardization of equipment by the replacement of an old wheeled tractor of American manufacture by the type chosen as the standard heavy tractor for the farm.

A new mounted sprayer capable of being used for both high- and low-volume work was bought, and it worked very satisfactorily.

Several other new items of equipment were bought to replace outworn equipment.

Buildings

The buildings planned for 1955 and the grain-drying and storage bins did not materialize. However, plans are well forward, and it is hoped to put them into effect early in 1956.

Estate Work

The hedge-cutting machine purchased in 1954 enabled all the hedges to be cut in a few weeks in early winter. Some new fences have been erected, and other general work has been done.

About 60 trees were felled in the winter of 1955–56, of which about half were dead or dying, while the remainder formed obstacles or were shading important areas of arable land. A small programme for replanting odd pieces of land is being drawn up.

The well at the farm which supplies the farmstead and cottages, and most of the fields, showed signs of drying up; the existing water supply system has therefore been joined up to the mains water. The well water will be used when available; the mains water will only be used when the well is unable to meet our requirements.

Purchase of Land

Two orchards totalling about 26 acres adjoining the farm boundary came into our possession in October 1955. The orchards

have been badly neglected, and are in a derelict state. A small part will be retained under fruit for observation by the scientific staff, but a start will be made with the grubbing up of the remaining area early in 1956.

Staff

Stephen Meyler, Deputy Farm Manager, resigned in January 1955 and was succeeded by M. J. Hill.

C. R. L. Scowen transferred from the farm staff to a post at the laboratories in April 1955.

H. P. Currant, a member of the farm staff since 1911, and farm foreman for many years, resigned in April 1955. W. A. H. Burton was appointed farm foreman in July 1955.

Woburn

The work of the Woburn Farm is directed and managed by the staff of the Rothamsted Farm. The field experiments are controlled by the Field Plots Committee, and the day-to-day planning is done by the bailiff at Woburn.

1955 was not a difficult year, but was disappointing in that all crops, except cereals, were adversely affected by the late, cold spring and subsequently by the severe summer drought. Crop yields are therefore well below average, and potato yields especially so.

The Effect of Weather on Crops

The very wet conditions in the early winter of 1954 resulted in all field work being far behind schedule by the beginning of 1955. In January and February only a very limited amount of field work was possible. However, by the end of March the ploughing was completed, and all the spring corn had been drilled by the end of the first week of April. The dry spell in April enabled good progress to be made, and by the end of the month all root crops were sown except for a few acres of potatoes, and other work was up to date.

The cold, wet weather in May delayed the germination of late spring seeds and retarded the growth of cereals and potatoes. The continuation of the wet spell into June made it difficult to keep clean the areas of sugar beet, kale and red beet, as the weeds took root again almost as soon as they were hoed up. The cereal crops improved wonderfully in late May and June, and looked very promising by the end of the month.

The hot, dry weather during July, August and part of September favoured the growth, ripening and harvesting of the cereal crops, but root crops suffered severely from the long-continued drought. This also delayed the transplanting of leeks, and made the ground so hard that the ploughing of stubbles was somewhat delayed.

October was much drier than usual, and the potato and sugar-beet crops were harvested under excellent conditions. During November and December the weather conditions favoured land work, and all ploughing was completed by the middle of December. By the end of the year land work was right up to schedule, a very different state of affairs from the previous year.

Cropping

Of the 127 acres farmed 17 acres were under wheat, 38 under barley and 21 under potatoes. Smaller areas of sugar beet, kale and lucerne were grown. This cropping scheme was very similar to that of previous years; two small areas of old grassland were ploughed up, one being put to spring wheat and the other being directly reseeded.

Ground chalk was applied to a further 11 acres in 1955 as part of the policy of bringing the pH of the non-experimental land up to a figure of about 6·5.

Field Experiments

The classical wheat plots were fallow during 1955, and will be fallowed again in 1956 in order to reduce the heavy infestation of twitch (*Holcus mollis*). The barley plots were cropped as usual, and the infestation of spurrey was less severe this year, probably as a result of spraying earlier with MCPA. However, parts of these plots are foul with *Agrostis gigantea*, another type of twitch, and the area is to be fallowed in 1956. In order to eliminate the differences between the plots caused by acidity, all plots were given a differential dressing of carbonate of lime to bring the pH status to about 6. The future of these two pieces of land is now under consideration by the Field Plots Committee.

The long-term rotation experiments were continued with only minor modifications. An expansion of the short-term experiments on cereals was made possible, as one of the self-propelled combine-harvesters at Rothamsted was available for the harvesting. Details of these experiments are given in the report of the Field Plots Committee.

General Notes on Crops

Wheat and barley

Only a very small area of winter corn was sown. The spring corn made a slow start because of the cold weather, but subsequently grew away well and looked promising throughout the summer. The two new varieties of spring wheat, Koga II and Peko, looked particularly well, and good yields are anticipated, with Peko probably yielding the better of the two. No lodging occurred this year, but severe damage was done by small birds on one experiment rather early in the season; rooks and pigeons also caused some damage to parts of plots on another experiment. Proctor and Herta were the two main barley varieties grown.

Harvest was completed in good time, and suffered very little interruption from the weather. One of the combine-harvesters from Rothamsted was used for the first time this year, which made harvesting much easier and quicker. Three large cereal experiments were dealt with in this way, also some non-experimental areas. Other corn was cut by binder and stacked in the Dutch barns, where it still awaits threshing. All combined straw was baled and was sold from the field. The early completion of harvest enabled the threshing of the experimental plots to be started earlier than usual, and the work was completed before the end of September.

Most of the cereal crops were sprayed with hormone weed-killers, some at a rather earlier stage of growth than recommended. The results were very satisfactory, a very high kill of weeds being obtained.

Potatoes

Both experimental and non-experimental crops were very disappointing, the only exception being the irrigation experiment. Here the crop looked vigorous throughout the season, even on the non-irrigated plots, and this is reflected in a yield of about 11 tons/acre on the control plots, increasing to over 20 tons/acre with full irrigation. On the six-course rotation experiment the crop looked starved, and some plots on the ley–arable experiment were seriously affected by potato-root eelworm. The non-experimental crop of King Edwards lacked vigour throughout the season, despite a useful dressing of dung and fertilizers. One precautionary spraying against late blight (*Phytophthora infestans*) was done, but the dry weather prevented the occurrence of the disease. There was a fair amount of cutworm damage to the King Edwards, while common scab was prevalent on the Majestics. The total yield of King Edwards was low, and the tubers were very small in size.

Kale and sugar beet

The very small acreage of kale grown on a rich piece of soil after fallow grew well despite the drought.

The germination of the sugar beet was very slow and uneven, and the plants were not fit for singling until mid-June. There was a severe attack by the mangold fly (*Pegomyia betae*) when the plants were in a very young stage, and this caused a severe setback. This pest was effectively controlled by spraying with parathion. The crop suffered from drought in the dry summer months, and severe wilting took place during the hot spells. Yields were below normal on most areas, and the roots were small and of poor shape. The sugar content was disappointingly low.

Market-garden crops

The cutting of spring cabbage started about 2 weeks later than usual, but yields were about average and quality was good. The red beet germinated unevenly, and weeds were only kept down with difficulty. Yields here were a little lower than usual. The leeks harvested early in 1955 made disappointing growth, and yields were much below average. Quite a number of plants went to seed during the winter. The planting out of the leeks for harvesting in 1956 was delayed until early August by the hard and dry state of the ground, and the plants had to be hand-watered twice to give them a start. The spring cabbage was planted out in September, but despite a dressing of aldrin, some cutworm and leather-jacket damage occurred.

Grassland

The cold weather in the late spring and the drought during the summer prevented rapid growth, and at no time did the grass give any indication of getting out of hand. In fact, keep was only just

sufficient, and the position was eased by having available late in the summer an area of grassland reseeded direct in the spring.

The hay crop was cut early in June, and unfortunately a spell of rather unsettled weather followed. The hay was therefore rather spoilt, but it was eventually baled and carted in reasonable condition. The yield was rather light owing to the slow spring growth.

Livestock

Cattle

The policy of buying in young store cattle and fattening them off the grass after overwintering in yards was continued. By the end of 1954 most of the cattle had been sold and a smaller number than usual were overwintered. A small bunch of Irish cattle were purchased in the spring, but there was insufficient keep to fatten them by the autumn. They were therefore brought into the yards to finish off.

Pigs

The Large White pig herd was maintained, and most of the progeny was run on to bacon weights. Home-produced food was used as far as possible. The results were disappointing, in that litter sizes and weights were rather low and final grading results were lower than in the last few years. In an attempt to remedy these matters the very unsatisfactory housing will be improved in 1956.

WOBURN EXPERIMENTAL STATION

H. H. Mann

Season

The year 1955 was in great contrast to 1954 in regard to the weather. After a very wet winter and spring (except for the month of April) the summer months of June, July, August and September were dry, leading to excellent corn crops but relatively small yields of roots and potatoes. The soils at Woburn are light, sandy loams, but they have, in nearly all cases, a fairly moist subsoil, which even in the driest summer allows deep-rooted crops like sugar-beet or lucerne to maintain fairly good growth. The only crops which really suffered from the drought were potatoes, where irrigation almost doubled the yield of the main crop, and grass, where, after good growth up to June, there was hardly anything to cut from July to October. The meteorological records from October 1954 to the end of 1955 are shown below.

Meteorological records for 1954–55

Month	Rainfall: Total fall (inches)	Rainfall: No. of rainy days	Bright sunshine (hours)	Temperature: Max. (° F.)	Temperature: Min. (° F.)	Temperature: 1 ft. in ground (° F.)	Temperature: Grass min. (° F.)
1954							
October ...	2·28	21	99·6	59·3	47·6	52·8	43·6
November ...	4·17	23	55·3	50·3	37·6	44·6	32·5
December ...	2·24	15	61·4	48·1	42·4	41·1	33·5
1955							
January ...	2·44	17	37·9	40·8	30·9	36·9	29·5
February ...	1·63	17	81·0	38·8	28·5	36·7	26·8
March ...	1·13	12	142·2	44·5	28·9	37·1	24·6
April ...	0·47	10	155·1	57·2	40·0	48·4	35·3
May	4·57	17	195·8	57·3	41·5	51·2	37·5
June ...	2·15	12	150·6	65·3	48·1	59·1	47·7
July... ...	0·19	2	242·2	74·0	51·6	65·7	47·8
August ...	0·70	7	170·6	74·0	54·4	66·0	47·8
September ...	1·65	10	158·2	65·9	48·7	58·3	44·2
October ...	1·79	13	115·1	55·5	40·4	49·4	36·0
November ...	1·26	14	52·1	49·6	37·5	43·9	32·8
December ...	2·28	20	61·1	48·0	35·4	41·0	31·9
Total or mean for 1955 ...	20·26	151	1,561·9	55·9	40·5	49·5	36·8

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that committee will report on them separately so far as the yields are concerned. There are, however, a few points in connection with them which may be recorded here.

Continuous barley

In this experiment (in which barley has been grown since 1877) it has been shown that the falling off in the yield of barley in recent years was, at least in part, due to the development of soil acidity. It is well known that the lime content of the Woburn soil is very low, and pH determinations plot by plot in 1953 and 1955 showed that in many cases the pH value had gone down below 5·0; it was therefore decided to treat the whole area with chalk in the spring of 1955 so as to bring the pH value to the original figure of about 6·0. This was done in three instalments, with cultivation between the applications, between 14 February and 6 April, barley being sown on 7 April. It would not be expected that the benefit of the chalk dressings would be immediate, but all the plots where the acidity had been at all marked did show considerable improvement, and in those which had been the least acid the crop was higher than for many years. It is not clear whether, when the chalk applications have been fully effective, the yields recorded in the early years of these trials will again be obtained, for the plots have become extremely weedy, especially with twitch (*Agrostis*), which is very common in this field. This point will be tested in the future years after a fallow in 1956 to get rid, as far as possible, of the twitch and other weeds.

Ley–arable experiment

This experiment, which has been going on since 1938, and is now yielding very valuable results as to the relative value of grazed leys or hayed lucerne leys and an entirely arable rotation, was continued in 1955. The results show regularly that the following crops of potatoes and barley are substantially better after each of the ley treatments. The results seemed now to be so clear that they could be published with confidence; but the discovery this year of an accumulation of potato-root eelworm in certain of the potato crops leads to some hesitation in the matter, and the result of a careful examination of the eelworm status of every plot in this experiment is now awaited.

Irrigation experiment

1955 was a year when the effect of irrigation would probably be felt to the greatest extent in increasing crop yield. The numerical results are discussed by the Physics department, but there are two or three points which may be mentioned here. The most outstanding increase in yield took place with the main crop potatoes (Majestic), when the plots which were watered throughout the season gave nearly double the yield obtained from the unwatered crop. The watered potatoes remained in flower for 10 days to a fortnight after the flowers had all disappeared from the other plots. This would probably account in part for the increased yield, and it was noticed on every one of the completely watered plots.

In the case of the grass plots which were sown with pure cocksfoot in 1954, it is interesting to note that practically all the weeds and weed grasses had disappeared by the summer of 1955. The *Poa annua*, which was quite abundant a year ago, has not been able to stand frequent cutting either on the watered or on the unwatered plots, and so has left an almost pure stand of cocksfoot.

Nitrogen fertilizers on spring wheat and barley

Experiments were conducted on the effect of increasing the application of nirrogenous fertilizer in the form of " Nitro-Chalk " from 2 to 4 and 6 cwt./acre, and on its application at different times during the growth of the crops. The results will be discussed elsewhere, but it is clear that even at 6 cwt. " Nitro-Chalk "/acre, the grain yield is still going up with both wheat and barley. The main point of interest in the experiment has been the mechanism of the increase; namely whether nitrogen increases the straw more than the corn, and whether the increase in corn is obtained by the presence of a larger number of ears, by an increase in the size of the ears or by a greater weight of the individual grains. Samples were, therefore, taken just before harvest and threshed by hand. Data were obtained on the number of ears per unit of row length, the weight of corn and the weight of straw for a similar length of row. The results are similar in the cases of spring wheat (Koga II) and spring barley (Herta), and indicate that when the nitrogenous manuring is increased beyond a very small dose, both grain and straw give a greater yield, but the straw responds far more than the grain. As an illustration of this the figures are given for spring barley (Herta) in 1955.

	Yield per acre		Percentage increase	
Manuring per acre	Grain (cwt.)	Straw, etc. (cwt.)	Grain	Straw, etc.
No " Nitro-Chalk " ...	21·4	12·8	—	—
2 cwt. " Nitro-Chalk " ...	32·4	22·7	51·6	77·1
4 cwt. " Nitro-Chalk " ...	41·4	33·6	93·6	161·8
6 cwt. " Nitro-Chalk " ...	46·9	44·5	119·0	247·3

Thus it appears that, with a large dressing of " Nitro-Chalk ", while the grain yield goes up by 119 per cent, the straw increases by double this amount.

It was found that the number of ears per unit length of row increased by 26 per cent in Herta barley with the first 2 cwt. of " Nitro-Chalk ", by 12 per cent with the second 2 cwt. and by only 2 per cent with the third 2 cwt./acre. On the other hand, the length of the ears increased very closely in proportion to the amount of nitrogenous fertilizer added. These result, which are only provisional, throw some light on the cause of the increase of yield by nitrogenous fertilizers.

Effect of manuring on weed herbage

The results of long-continued observations on the weed herbage of land farmed with large amounts of bulky organic manures have been compiled during the year, and will shortly be published. The manures were farmyard manure, sewage sludge and composts made with straw activated with dung or with sewage sludge. The observations have shown very little difference in the effect of the various manures on the character of the weeds, but in all cases the use of the organic manures has led to an increase in the weeds of about 30 per cent. Doubling the amount of the bulky manure has not further increased the weediness, except in the case of the annual nettle, which flourished most where the organic additions were greatest. Perhaps the most striking effect was produced by even a slight change in the acidity of the soil. It was remarkable how

spurrey (*Spergula*) and even mayweed (*Matricaria*) disappeared when acidity was reduced by the treatment, and how they immediately came in again when the land became more acid. The results of this work will be shortly published in the *Journal of Ecology*.

New crops

The work of testing the suitability of new crops, chiefly semi-tropical ones, for this country has been continued. The summer was warm but not hot, and the drought which prevailed for most of July and August had a large effect on the growth and success of this year's crops. The investigations have chiefly been concerned with types of hybrid maize, of soya beans as developed in Sweden, of a type of Jerusalem artichoke developed as a fodder crop and of fodder crops suitable for semi-acid soils such as at Woburn.

Maize

Some of the early hybrid types of maize of either American or Dutch breeding can now be confidently recommended for growing under suitable circumstances in this country. In 1955 between 25 and 30 cwt. dry grain/acre has again been obtained from two Dutch types known as C.I.V.2 and C.B.30, in a year when the crop had a bad start in the cold May, and then had drought conditions from the beginning of July. The crop, however, ripened perfectly and, contrary to what we have found in our usual wet autumns, could be harvested without any serious danger of the cobs going mouldy in storage. We have been trying to grow maize for grain since 1934. At first we used old Canadian types and failed completely to get varieties which were much use in England. Either they ripened well but yielded badly or they were not able to ripen in our damp, cool summers. With the introduction of early hybrids, originally obtained from Wisconsin (U.S.A.), but now developed and improved in Holland, the position changed. Since 1948, we have been able to get yields every year (except 1951), which make the growing of these hybrids practical in this country. The yields are as follows :

1948 (Wisconsin 240)	... ...	27·5 cwt./acre
1949 („)	... ...	33·8 „
1950 („)	... ...	36·6 „
1952 („)	... ...	38·0 „
1953 (Dutch) ...	... ...	31·0 „
1954 (Dutch C.I.V.2)	... ...	41·7 „
1955 („)	... ...	28·0 „

The mean yield of all the crops quoted is 34·7 cwt./acre, and has been obtained on ordinary farm land with never more than a manurial dressing of 3 cwt. of sulphate of ammonia or " Nitro-Chalk " per acre. In order to obtain these yields it is necessary to get fresh seed each year, as we have shown that the use of our own seed for a season gives considerably lower yields. The period of growth of all the hybrids is very much longer than in the countries where they have been developed, probably owing to the cooler summers that we have in England. The falling off in yield in 1955 is probably due to the maize ears being smaller than in previous years owing to the long drought in July, August and September.

Soya beans

We have also been experimenting with soya beans since 1934, at first with varieties brought from Canada coupled with others which had been developed by pioneers in this country and the United States. But all the varieties either never ripened or gave such small yields that it was clearly not worth while growing them. The best yield of dry beans was 14·5 cwt./acre from an American variety until, 5 years ago, seed was obtained from Sweden, where types had been produced which seemed to have more promise than any available elsewhere. The results found from 1949 to 1953 seemed very promising, and though the best yields were from 10 to 11 cwt./acre, it seemed possible that by closer planting of these dwarf varieties the yield could be pushed up to a profitable point. The cold, wet season of 1954 was, however, very unfavourable for soya beans, hardly any seed ripened, and what did ripen was very inferior. The same seems to have happened in Sweden, where the breeders reported that they also had great difficulty in getting good seed. They, however, sent a small amount of seed of several strains which we tried to grow in 1955. With the inferior seed and a cold May after the seeds were planted, they never came to anything, and we are losing confidence in the possibility of growing any of the types now available for the commercial production of soya-bean seed in England. It is only the dwarf types which will ripen in this country, and the production of seed of these varieties is so uncertain at present that there does not seem to be a type that can be recommended.

Exotic fodder crops

The other side of the work on exotics is concerned with fodder crops suited to semi-acid soils, which will grow quickly to give a heavy crop of attractive fodder in September or October, when the grass crop is declining in quantity. In last year's report *birdsfoot trefoil* was mentioned as one of the best crops of this class. It has the additional advantage of being a perennial, lasting two or three years for one seeding, and will grow in less fertile soils than ordinary red or crimson clover. Two other crops have given so much promise that the time seems ripe for their use on a larger scale than hitherto. These are *Sweet Lupins* and *Serradella*. We have sufficient experience with each of these crops to expect them to grow in any summer that is likely to occur. In this sense, the last two years have been a great test. 1954 was cold and wet; 1955 started with a wet and cold May, but had a drought from July to September. The effect of the drought in 1955 was shown in very much reduced crops, especially with sweet lupins, but in both seasons the crops grew healthily and yielded good fodder. The actual weights of fodder are shown below.

	Wt. green stuff per acre (tons)	Dry matter (%)	Dry matter (tons)
Sweet Lupins (variety *Weiko*) :			
1954	16·1	9·6	1·55
1955	3·03	14·9	0·45
Serradella :			
1954	14·7	11·5	1·69
1955	4·96	24·4	1·21

It will be seen that in the case of both these fodder crops the drought of July and following months in 1955 has very much reduced the yield per acre. This was to be expected, as the crops were not sown till 6 June to see how quickly a crop of fodder could be obtained. The fodder was far drier than in 1954, as would naturally be expected.

Artichokes

Another new crop of considerable interest is the so-called "*Topine*", a strain of Jerusalem artichoke which is reputed to be specially luxuriant and consequently of special importance for fodder. The results of our first year's experience with this crop in 1954 appeared to be promising, for we had nearly 18 tons of green stuff in October from tubers planted at the end of April. The tubers from that crop were dug in February and March 1955 and gave a yield of 8 tons/acre or 0·73 lb. per plant. The present year was a good test of the capabilities of the crop on account of the drought. Tubers were planted on 26 April and grew well, giving plants which were more bushy and rather shorter than in 1954. They showed little or no sign of suffering from the drought till near the end of October, when the tops seemed slightly drooping, while the leaves were somewhat damaged by a severe frost on 16–18 October. The crop was cut on 31 October, when 9·4 tons of green tops per acre were obtained containing 30·1 per cent dry matter. This means a dry matter yield of 2·82 tons/acre, as against 3·34 tons/acre in 1954. Thus the reduction due to the drought was only moderate as compared with that given by the other fodder crops tested. The yield of tubers has not yet been determined, as they will be left in the ground till February, for they cannot be clamped like potatoes. On present information artichokes still appear to be promising. It has been proved in many tests in the United States that the tubers compare very well with potatoes as a food for pigs.

Laboratory Work

Among the more interesting pieces of work that have been completed in 1955 has been a study of the permanence of organic matter in the soil when applied from various sources. This work has been based on experience with a field experiment in which large quantities of bulky organic manures, including farmyard manure, sewage sludge and composts, had been added to market-garden crops for a series of years. Material for 8 years was available, and the conclusions reached were that: (1) The materials divide themselves into two classes. On the one side is farmyard manure, in which the organic matter appears to be considerably more active than in any of the other materials used and so disappears more quickly. The least active is that contained in sewage sludge. In composts made with farmyard manure the addition of more straw slowed down the rate at which the organic matter disappears. (2) Except with farmyard manure the addition of sulphate of ammonia slightly retarded the disappearance of organic matter. Doubling the amount of organic manure applied led to its more rapid disappearance, except again with farmyard manure.

Work on the pot-culture station and in the laboratory has been

again restricted in 1955 by the demands of the irrigation experiments, and has hence been almost entirely concerned with control of the field experiments. Most of this work falls on Mr. Barnes and his staff, and they have been fully employed in these directions during the year.

TROPICAL SOILS

H. Greene

H. Greene visited the Gold Coast and the Gambia in March 1955. In the Gold Coast, members of the Department of Soil and Land-Use Survey, directed by Mr. C. F. Charter, have observed a pronounced lack of magnesium in strongly acid soils which have failed to support cacao. On the other hand, cacao has survived on less acid soils having a higher content of magnesium. That young cacao plants grown in containers need magnesium had been demonstrated in the Belgian Congo by Professor M. V. Homès. These observations throw a welcome light on the nutritional needs of this important crop. Greene also visited the Kpong Irrigation Research Station, which is within the extensive black clay region of the Accra plains. Successive showers were preventing tillage of the sticky soil : tests will show what crops can be grown in spite of the difficult physical conditions. Detailed and reconnaissance soil surveys have been carried out here. Under the direction of Professor J. F. V. Phillips, work has begun at the Nungwa Agricultural Research Station which includes red sandy loams and grey sands, as well as the dark clays of the Accra plains. Large responses to N and P fertilizers have been obtained on the grey sands.

In the Gambia, Dr. R. A. Webb of Long Ashton has been able to demonstrate by means of pot experiments severe nutrient deficiencies in the reddish acid sands which have received no fertilizer in spite of repeated cropping with groundnuts. To make the new information of use to the cultivator, field experiments are needed, but lack of staff for this purpose created difficulties which were discussed in the Gambia and in London.

Greene attended the 9th and 10th sessions of the UNESCO Advisory Committee on Arid Zone Research which were held in Arizona and New Mexico (April, May 1955) and in Paris (November 1955). This committee recommends to the Director General of UNESCO the allocation of grants for studies in the plant ecology, animal physiology and climatology of arid regions. Grants are also made for training, for the publication of reviews and for the holding of symposia. A symposium on Arid Zone Climatology with special reference to microclimatology is to be held in Australia in October 1956. For the next few years the plan is to concentrate attention on problems of arid areas in the Near East and South Asia. The 9th session of the Advisory Committee was held in conjunction with an International Arid Lands Conference organized by the American Association for the Advancement of Science. Local interest was increased by the fact that the discussions were preceded by a punishing succession of dry years. After the meetings, Greene visited irrigation and drainage projects in California and Utah. Post-graduate training in irrigation and drainage is offered by the U.S. Bureau of Reclamation; help with salinity problems is offered by the U.S. Salinity Laboratory at Riverside, California.

A sub-committee which advises the Colonial Office on soil

problems recommended soil survey in Swaziland where irrigation is being developed. G. Murdoch, a member of the recently constituted pool of soil surveyors, has accordingly been seconded to Swaziland, and Greene went with him in October 1955 to help in getting the soil survey started. Greene was also able to discuss with Col. C. J. van Heerden and with Mr. A. C. Venn the extension to Swaziland of field experiments with fertilizers that have been so fruitfully initiated in Basutoland by Mr. Venn. Greene also visited Basutoland. During the past 15 years, soil conservation has made good progress in Basutoland, but there are still many gullies and in these there are striking exposures of solodized solonetz, a kind of soil first described in south Russia. In Mr. Venn's experiments with maize, this soil responds to lime as well as to phosphate and dung. Mr. Venn will now begin rotation experiments, probably including legume and cereal crops. This work will effectively support and supplement progress in soil conservation.

In early November Greene revisited the Sudan after an interval of 10 years and found that field experiments with irrigated cotton at the Gezira Research Farm were being carried out with faultless precision. The late Dr. E. M. Crowther helped to introduce into the Sudan the new techniques of field experimentation soon after they were used at Rothamsted and, over a period of years, this influence was maintained by his brother, the late Dr. Frank Crowther. As a result of this, the Sudan has about thirty years' start on territories like Swaziland or the Gambia in this essential and remunerative work. It seems, however, that in the Sudan there is need for further research in plant pathology, plant physiology and soil microbiology, and at present difficulties of recruitment, though not peculiar to the Sudan, have been accentuated by Sudanization of various Government services. This is a particular case of a general and urgent problem : much thought is being given to ways of maintaining the flow of technical aid to underdeveloped countries. If help in scientific research can be given and accepted without provoking antagonism it may go far towards easing social tension as well as achieving practical results.

Recruitment of scientists for soil work in British colonial territories has lagged only a little behind current needs. The creation of " pools " based in this country has helped to secure some young graduates, who, after further training, are available for short-term jobs overseas, and who may accept long-term appointment where that proves convenient.

When at work overseas, soil scientists are liable to lack easy contact with professional colleagues. In order to alleviate this isolation the Adviser on Tropical Soils sends out occasional circulars containing notes on books, equipment and items of soil news. Thus it was reported that a substitute for the expensive porcelain vessels used in pot experiments is provided by polythene tubing within a strong brown-paper bag. These Kraft–polythene containers, which can be sent by post, are supplied in two sizes by Messrs Bennett Bros., Counterslip Works, Bristol. They may permit tests for nutrient deficiencies in places where it is difficult to get porcelain pots. The value of such tests has recently been demonstrated by Dr. R. A. Webb in the Gambia and by Dr. E. M. Chenery in Uganda. Among the news items circulated were notes on soil surveys carried

out near Ilesha (Nigeria), Mbosi (Tanganyika), Lower Rufiji (Tanganyika), the Trans Perak Swamp (Malaya) and on the Land-Use Survey in British Honduras. A note on the preparation of fresh water from salt reached Dr. H. C. Pereira just after he had received an enquiry about the possibility of processing the brackish water of Lake Rudolph. Other correspondents may have had no interest in that subject, but on the whole they seem to like the snippets of news that are sent round to them in this informal way.

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

The Soil Survey has sustained the loss of two members of the staff. Early in the year C. J. Tapp died, who, although one of the less experienced members, had shown considerable promise, being a conscientious worker and a cheerful companion. Somewhat later, E. Crompton resigned to take up a post in the University of Durham at King's College, Newcastle-upon-Tyne. He was one of the most experienced surveyors and had contributed much to the development of the Survey and its application to practical problems. A new centre has been started at Newcastle, and four new surveyors have been recruited and posted to various stations.

A. Muir represented the Agricultural Research Council on a British Delegation to Russia, and L. F. Curtis has returned from Iraq to be stationed in Derbyshire. A. Thomasson has been granted leave to assist in the completion of the Iraq survey started by L. F. Curtis. J. Harrop has also been granted leave to take part in a scientific and mountaineering expedition in the Himalayas. The Colonial Pool of Soil Surveyors has been increased to six members, two of whom are training with the Soil Survey of England and Wales. A. O. Ballantyne is making good progress in the area he is surveying in Northern Rhodesia, and G. F. M. Murdoch has started surveying in Swaziland. C. A. H. Hodge completed the work started last year in Aden and has now gone to Somaliland for a short period. Several members of the National Agricultural Advisory Service spent considerable periods with members of the Soil Survey in the field. During the year C. D. Ollier (Colonial Office Student) and G. Higgins (N. Nigeria) received training in survey techniques. Professor B. Vovk (Yugoslavia) and Professor W. Kubiena as well as other visitors spent varying periods with the surveyors seeing the work being done.

In spite of the long, dry summer and the necessity for checking and revising parts of completed sheets, the survey's progress has been maintained and an additional 270 sq. miles have been surveyed. Mapping has been completed on Sheets 75 (Preston), 188 (Cambridge) and 238 (Aylesbury). Surveys have been started on Sheets 94 (Llandudno), 106 (Bangor) and 176 (Ely), while work has continued on Sheets 280 (Wells), 166 (Church Stretton) and 305 (Folkestone).

Mr. E. Roberts, of the National Agricultural Advisory Service, who, with the late D. O. Hughes, surveyed a large part of Anglesey, has written a memoir on the county's soils and agriculture to accompany the soil map which will be published on Sheet 106 of the New Popular Edition. He has also undertaken to write a similar memoir of the Lleyn peninsula which will be published on Sheet 115 (Pwllheli) of the same edition. Another memoir " The Soils of the Glastonbury District of Somerset (Sheet 296) " was published during the year.

Lancashire

Sheet 75 (Preston)

The small areas of high moorland have been surveyed and some revision has been carried out elsewhere. The mapping of the alluvial deposits in the Ribble and Douglas estuaries revealed a complicated soil pattern of differences in drainage and texture as well as content of calcium carbonate, the latter being probably related to both the depositional patterns and changes in relative levels of land and sea. The detailed mapping of this sheet has revealed a complex soil pattern which is almost impossible to reproduce on a 1-inch map and some of the most complicated area will be published at the 2½-inch scale. (A. Crompton, G. D. Ashley, B. R. Hall.)

Somerset

Sheet 280 (Wells)

The illness and subsequent death of one of the surveyors considerably reduced the speed of progress, and field work was primarily directed to completing the mapping on the Old Red Sandstone and Carboniferous Limestone on Mendip, where Black Down is of particular interest in having some of the only remaining natural vegetation in the district. In addition, about 20 sq. miles were surveyed in the coastal area around Highbridge of the adjoining Sheet 279 (Weston-super-Mare), where the Wentlloog series is very extensive. A 2½-inch map of the sheet has been compiled and found of use in demonstrating soil patterns not readily seen on the 6-inch field slips. (C. J. Tapp, D. C. Findlay.)

Shropshire

Sheet 166 (Church Stretton)

Mapping has been confined mainly to the Brown Clee Hills and the Longmynd. On the lower slopes of the former (the Dittonian platform) the most extensive and most important agricultural soils are those of the Bromyard and Eardiston series. The Clee beds give rise to a dull brown sandy loam beneath bracken and poor grasses that provide poor spring grazing for sheep. Above 1,500 feet gley and peaty gley soils appear on Coal Measures shales and sandstones and under sphagnum, rushes and mosses are found completely waterlogged and markedly gleyed soils without any development of peat. The summit is capped with olivine–dolerite, which gives rise to 1–2 inches of a tight bilberry and grass mat overlying 3–4 inches of grey silt loam followed by bright orange-brown silt loam.

The plateau of highly dissected Pre-Cambrian rocks forming the Longmynd is covered with heather with subordinate bilberry, while the valley sides are often bracken- and grass-covered, with grasses becoming dominant as the slope increases and the soils become shallower. The soils are peaty-podzols, associated with heather and bilberry, brown earths, some of which show very slight podzolization, which are associated with bracken and subordinate heather and bilberry, and gley soils with mosses, sphagnum and rushes. Shallow soils resembling those of the three groups are also found on the valley slopes.

The use of aerial photographs has enabled the distribution of vegetation and hence the soils to be more easily mapped on a reconnaissance basis, and has aided in the identification of sites of gley soils. They have also been used to delimit areas of steep slopes. (D. Mackney, G. F. M. Murdoch.)

Cambridgeshire

Sheet 188 (*Cambridge*)

Owing to the unusually dry weather, the absence of one of the team in Aden and the subsequent time needed for reporting on that work, the rate of progress has been reduced. In addition, the annual Field Meeting was held at this centre, and the work involved in preparing for it left the only surveyor little time for routine surveying. However, some of the earlier work on the sheet was checked and, where necessary, revised in the light of later findings. Thus the sheet has been completed and the writing of the memoir and compilation of the map has been started. A beginning has also been made on the mapping of the adjoining Sheet 176 (Ely). (R. S. Seale, C. A. H. Hodge.)

Hertfordshire and Buckinghamshire

Sheet 238 (*Aylesbury*)

With the mapping of about 80 sq. miles the survey of the sheet has been completed. On the Chilterns especially, mapping became extremely difficult on account of the dry summer, and attention was given to digging profile pits, forty-four of which were described and sampled for analysis. Several new series have been identified, associated, on the Chilterns, with the so-called " glacial sands and gravels " near Watford, and, in the Vale of Aylesbury, with the clays, glauconite sands and limestones of the Upper Jurassic (Kimmeridgian and Portlandian) formation. (B. W. Avery, D. W. King, A. J. Thomasson.)

Yorkshire

Sheet 70 (*Leeds*)

Some revision of earlier work has been undertaken, and altogether about 30 sq. miles have been mapped. The remaining area needed for completion of the map consists mainly of two blocks, one east of Leeds along the southern edge of the sheet to Garforth, and the other along the easern edge, south of the Wharfe. No new series have been encountered either on the Magnesian Limestone, the Millstone Grit or Carboniferous sandstones and shales and related tills.

The dry summer emphasized differences between soils, particularly those on the drifts associated with the York and Escrick moraines. As might be anticipated, the sandy soils did not crack noticeably, but loams had cracks up to an inch wide and clay loams up to about 1½ inches, so that this feature became, temporarily, almost diagnostic of the soil series. In an area of silty clays, alluvial in origin, and poorly or very poorly drained, cracks of 2–3 inches wide were seen, particularly in the bottoms of the

furrows where the land had been ridged. In some places the surface was irregular in a manner suggestive of " self-swallowing " or gilgai phenomena.

In the Eccup and Harewood district some 5 sq. miles were mapped on the 2½-inch scale for comparison with a 6-inch map previously made by another surveyor. The smaller scale allowed over twice the rate of mapping, but accuracy was sacrificed, especially of those boundaries not easily deduced by indirect means, such as a consideration of landform. (A. Crompton, L. F. Curtis.)

Caernarvonshire

Sheet 94 (*Llandudno*) *and 106* (*Bangor*)

Parts of these sheets had been mapped before and during the war by workers from Bangor, and about 46 sq. miles have been surveyed and checked. In the Creuddyn peninsula, intermingling of material from small outcrops of volcanic rocks and larger areas of Carboniferous Limestone over which is spread a drift of Silurian shale from the landward and of Triassic material from the seaward side, makes the soil pattern very complicated. Two new series have been recognized, but the other soils present have been described on the Rhyl and Denbigh sheets.

In the Conway valley, series previously described on the Silurian shales and associated drifts have been mapped on the extensive alluvium bordering the river. On the west side of the valley the soils are derived from Ordovician rocks, and drift from the acid igneous rocks of Snowdon also begins to affect the soils.

Some time was also spent checking boundaries and sampling profiles described on Sheets 95 (Rhyl) and 107 (Denbigh) the mapping of which was completed last year. (D. F. Ball, J. Harrop.)

Derbyshire

Sheet 125 (*Derby*)

Owing to previous commitments in other areas, work on the survey of this sheet has been restricted, and mapping has been completed on the 6-inch scale of about 8 sq. miles in the Sandiacre and Little Eaton districts. A preliminary classification has been prepared of the soils developed on the Triassic, Lower Coal Measures and Millstone Grit formations and the associated drifts, but no attempt has been made to name series, except where correlation with previously described series is certain. (J. H. James.)

Kent

Sheet 305 (Folkestone)

Approximately 37 sq. miles have been surveyed, mostly at something less than the normal intensity for 6-inch mapping. In view of the complex and contrasting soil distribution found earlier, the policy has been to obtain a general picture of the extent of the various deposits, to determine the soil units and to map the natural soil patterns.

The surface deposits range in age from 3,000 to 400 years or less, and it has been shown that these exist in at least four distinct

landscape units, each associated with a particular soil pattern. Some units apparently merge imperceptibly, while others can be sharply delineated. In each unit there are distinct profiles ranging from sandy loams to clay, with important differences between them in carbonate content, structure, salinity and depth to peat or shingle.

Water-table levels for a number of soils are now being measured monthly, but a complete season's records have not yet been obtained. It is expected that the results will throw light on the use that can be made of the different gley-phenomena as indicators of drainage conditions, and they should also give an indication of the right order of water-table levels for optimal performance of pasture on some soils. The only useful statement that can be made at present is that the fluctuation of the water-table this year within some soils has been of the order of 3–4 feet. (R. D. Green.)

Other Work

Following the severe flooding in 1954, when 18 sq. miles of mossland in South-west Lancashire were affected, a request was made for a survey of the area. In all, about 31 sq. miles have been surveyed on a grid-system, with borings made every 400 yards on parallel traverse lines $\frac{1}{3}$ mile apart. The peat deposits stretch from the River Alt in the south to Blowick and Scarisbrick Moss and then reach northwards and eastwards to the vicinity of Tarleton. The main findings can be summarized as follows :

(1) The thickness of the peat varies considerably, ranging from a few inches to 20 feet. The peats have been grouped into four main classes.
(2) The mineral soil beneath the peat has been described, information which will be most useful in future drainage operations.
(3) The mapping and classification of the surface soils will assist in the interpretation of the results obtained from experimental plots which will be laid down to study problems of management, manurial requirements, pest susceptibility, etc.
(4) Areas of mossland reverting to an unproductive state and those which have not been reclaimed will be delimited. (B. R. Hall.)

The problem of restoration of sea-flooded soils on the Lindsey coast has been examined in detail. The presence of three main textural groups has been established, silty fine sands, silt loams and clays, and in each group there has been a marked movement of the clay fraction down, and sometimes out of, the profile. This has resulted in a complete change in the profile, with loss of structure and the development of impermeability. Since the present treatment of the soils with gypsum is inadequate in replacing sodium with calcium in the clay, further experiments are being carried out to find a more effective means of stabilizing and restoring soil structure. (E. Crompton, G. D. Ashley.)

A further survey was made of the natural drainage classes and the variability of the parent materials on a 3,000-acre farm at Apesthorpe for the National Agricultural Advisory Service. Advice

was also given to the same body on the possibility of drilling for water for irrigation in the Melbourne district in Derbyshire. Some mineralogical work was carried out for the Air Ministry at the request of the East Midland Provincial Director of the National Agricultural Advisory Service.

A number of visits have been paid to ironstone workings to examine the rate of weathering in limestones and, in particular, three sites have been investigated. Detailed studies are being made of the rate and type of weathering in relation to the lithology and size of the limestone blocks. (J. H. James.)

At the request of the Welsh Land Sub-Commission, a survey was made of the parishes of Llangurig, Llanbister and Llanddewi-Brefi, covering about 100 sq. miles in central Wales. The rocks are of Silurian age, dominantly shales and mudstones with locally important grits and sandstones, and previously established series only were required to map the soils developed. Peaty gley and peaty podzolic soils were extensive in Llangurig and Llanddewi-Brefi, but in Llanbister uncultivated land at 1,300–1,400 feet O.D. and more showed no evidence of peat formation or development of podzolized soils. (D. F. Ball, J. F. Harrop.)

The farm at Askham Bryan of the Yorkshire Institute of Agriculture was surveyed at the 6-inch scale. Some of it is situated on a morainic ridge with heavy but gravelly soils and sandy, gravelly soils above spreads of fluvio-glacial sand on the gentle slopes below them. The lower parts of the farm consist of the Wighill and Deighton series, the poor drainage of which has been improved. At the request of the Ministry of Agriculture, Levens Hall Farm, near Harrogate, was surveyed at the 25-inch scale. The soils are developed on Carboniferous till, and are mainly sandy clay loams and clay loams. On the higher ground the soils are freely drained, but in general they are poorly drained. (A. Crompton.)

Various members of the survey have collected properly characterized soil samples for use in antibiotic studies by Imperial Chemical Industries.

At the request of the Road Research Laboratories surveys were made along the proposed routes of the new roads, by-passes and widenings to be undertaken in various parts of the country. Eight reports (one by Oxford University) were submitted and were forwarded to the Ministry of Transport and Civil Aviation.

ECOLOGICAL ASPECTS OF APHID FLIGHT AND DISPERSAL

By

C. G. Johnson

General Approach

There are two main aspects in the dispersal of insect populations: the process itself, and the significance of dispersal in the evolution and abundance of a species and in its status as a pest. We recognize, however, that both these aspects are part of the same ecological system and interdependent; and that the mechanics of dispersal can be fully appreciated only if placed in an ecological context.

This brief review considers the dispersal process itself in this way, as it concerns aphids: and deals particularly with some recent contributions, some of them unpublished, from Rothamsted.

In the past, especially in Britain, dispersal, and many other aspects of ecology, have often been studied by trapping flying insects and correlating numbers caught with weather factors. Usually this was done with a single trap a few feet above the ground, emptied once in 24 hours or even less frequently. This is very valuable for some predictions; but it is inadequate for an analysis of the biological and distributive processes in dispersal.

Trap data alone neglect the events in terrestrial ecology on which aerial abundance and so dispersal primarily depends. In fact, a trap abstracts the aerial situation from its ecological context, while a single trap at one level, emptied once a day, is an exceedingly blunt instrument for dissecting a process which extends hundreds or thousands of feet into the air and operates on an hourly rather than a daily time scale. This approach with aphids has kept alive for 20 years an erroneous hypothesis of dispersal which will be discussed later.

Nevertheless, trapping is necessary for measuring aerial density, if not always for analysing it; and a most necessary task was to improve the technique so as to relate numbers caught to the volume of air sampled and to record changes in density at hourly, or even shorter, intervals. Segregating suction traps have been developed to do this (C. G. Johnson & Taylor, 1955 *a* and *b*). Aphid dispersal, then, to be seen synoptically, must be studied both in relation to the insects on the crop and in the air as high as techniques will allow. This we have done, for the first time; and this article tries to put the whole study into focus.

It is helpful to consider the problems in three stages: the variations in numbers first liberated into the air from a primary source of supply and by subsequent flights; the dispersal of the insects through the atmosphere; and events leading to the return of populations to the earth and to alighting. Each stage has its collective, and also its individual, physiological aspects, which will be considered in the appropriate order.

Aphid Life History

Readers unfamiliar with aphids may be helped by a general account of the life history: though the number of exceptions is bewilderingly great.

Dispersal is mainly by winged aphids (alatae) which often fill the air in millions. There are in general three main waves of dispersal during the year: in spring, summer and autumn; each builds up to a maximum and declines, and lasts from about 1 to 6 weeks. Though sexual forms occur (either male or female, or both, may be winged), most dispersal is by females, which reproduce without being fertilized and lay not eggs but small fully formed, immature aphids. These aphids cast their skins four times before becoming like the parent, parthenogenetic, viviparous adult females, which may be winged or not. Several generations a year may be produced. The proportion of winged (alate) to non-winged adults usually increases in dry weather and as plants get older. Sexual forms are often produced in the autumn, and the winter is often spent as eggs.

Some species attack a large variety of plant species, others are confined to one. Some species alternate regularly between different plant species in summer and autumn, the sexual generation being commonly found only in certain plants in the autumn.

Variations in Numbers Migrating

A slight wind delays an aphid from taking off; and highest densities are commonly seen in calm weather. This has lead to the hypothesis that there is little dispersal above certain " optimum " weather conditions and that the amount of dispersal is controlled principally by weather acting on flight behaviour. Our results were at variance with this in nearly all respects (C. G. Johnson, 1954).

There are usually two elements in any change in numbers of insects flying; a changing population level and changes in the proportion of a population flying due to behaviour. In a human population the number of people on the streets from hour to hour is due to variation in behaviour not to population change; some insects are similar. But with aphids the population level of alatae changes so rapidly that it swamps behaviour in causing changes in numbers flying even from hour to hour. It is as if we produced a new family of immoderate proportions every time we went out for a bicycle ride and took them with us on subsequent occasions; and to understand what was happening we should have to investigate events at the source rather than by counting the people in the street. Similarly, if an insect trap is set up without care that it is near a primary source of alate production it catches many species of all sorts of ages indiscriminately, and the picture is blurred. But if we start at the beginning with a trap over a well-infested crop, producing large numbers of winged aphids, a clearer picture emerges (C. G. Johnson, 1952).

One of the characteristic features in the change of aerial numbers above such a place in the summer are the two peaks of relatively high density, one usually in the morning, another in the afternoon; and the virtual cessation of flight at night. It is not possible to

explain this in terms of flight behaviour alone; two other factors operate. These are the changing rate of production of new alatae throughout the day and night and the permanent departure of these insects after the first take-off. This is the real cause of the periodicity.

The penultimate stage in alate production is the nymph: these moult with a marked periodicity into winged, parthenogenetic females which pass through an obligatory maturation period (from about 6 hours to 2 days) before flying away. For an analysis of density change above the crop these three stages, moulting periodicity, length of maturation period and the flight behaviour, had to be measured as they occurred consecutively in a natural population. This was done in 1952 with *Aphis fabae* in collaboration with L. R. Taylor and Dr. Else Haine.

Starting very early in the morning, the hourly rate of moulting was recorded on selected plants. On others all newly moulted alatae were marked, but with a different colour, every two hours: their departure time was noted and their maturation period found (the maturation period occupied almost the whole time between moulting and flight). The total number marked was about 3,000 during the 2½ weeks work. A suction trap gave the aerial picture; wind-speed and temperature were recorded every half-hour.

The maturation period is governed mainly by temperature, to which it is related in a typical sigmoid fashion. By using hour–degree developmental units it is now possible to estimate the length of the maturation period when the temperature is varying as in the field. Variation in this, together with the time of sunrise and sunset and the temperature threshold for take-off, can be used to reconstruct model curves of density change for any day which match with a satisfying accuracy those observed for the same day with a suction trap, whether they have one or more peaks. A full account of this process will be published shortly.

The basic pattern of flight rhythms is thus not caused by previous moulting rhythms as once suggested (C. G. Johnson, 1954). But there is a pronounced peak of moulting in the early morning, and there is no doubt that variable moulting rates modify the shape of the flight curve, and we are now able to assess this. The flight periodicity is therefore largely a population–developmental effect, weather-controlled flight behaviour playing a minor rôle except at the beginning and end of the day The causes of rhythms in moulting of nymphs into alatae are not fully understood: but they too may be due to a "piling up" of fully developed instars owing to variable rates of development. Haine (1956) has found that these rhythms persist even at constant temperatures; it is probable too that similar rhythms exist in other phases of aphid life—e.g., in parturition.

Summing up this aspect of the work, we can say that the basic causes of aerial density change from hour to hour and day to day (seasonal fluctuations are outside the scope of this review) over a source of alate production are now, in the main, understood for one species, *Aphis fabae*; and that, given only the hourly temperatures and times of sunrise and sunset, we can reconstruct the aerial density curves theoretically. Variations on the general pattern may be important, and other species need investigation to see if they agree

with *A. fabae*. The first phase in the dispersal story is, to this extent, resolved.

But the analysis I have just described deals only with aphids flying away for the first time. It may be asked, do not all the subsequent take-offs of the gradually accumulating numbers of differently aged aphids swamp the limited number of first fliers? And does not the old hypothesis of weather-induced variation in take-off come back into its own?

There are several reasons why the old hypothesis cannot be re-established: with many species flight is limited to about 2–5 days by muscle autolysis (B. Johnson, 1953); the double peak often occurs well away from the source and suggests a limited degree of flight. Recent work by Haine (1955) has shown that while wind delays flight it does not prevent it, and several species of aphids can take off in considerable breezes (e.g., up to 7 m.p.h. for *A. fabae*); thus, in view of lulls and shelter in the field, wind is probably not a very important deterrent to flight except momentarily.

Moreover, because alatae production and flight is a continuous process during the day, and there are more windy occasions than calm ones, most dispersal actually occurs in winds from 5 to 20 m.p.h. (C. G. Johnson, 1954) not in the calm as once believed.

Müller & Unger (1954) interpret the double-peak periodicity of catches in yellow tray traps to variation in "alighting flight" (*Befallsflug*). This, we feel, is more likely to be reflection of the general density pattern rather than a variation in behaviour.

The Dispersal of Aphids through the Atmosphere

It is well known that aphids reach great heights in the air; and we have shown that the majority flying are usually above about 100 feet. The aerial populations are frequently of astronomical proportions.

However, there seems to be a general idea that the aphids in the upper air are of no great significance in the general ecology of these insects. This is because it is assumed that either they die when carried aloft or come to nought elsewhere: it is thought that the important aphids are those few which manage to avoid these unfortunate excursions.

We do not take this view. Aphids do not die merely by being carried into the upper air: these aerial populations are alive. And though many of the individuals may never find host plants and survive to continue the race, nevertheless this kind of dispersal, and the behaviour which accompanies it (upward flight at take-off and subsequent flight in relation to host acceptability (see p. 198)), is of a kind to which the whole life and evolution of the species is attuned. There is no evidence which justifies the belief that it is a few which behave in some other way which are the only ones which need be considered.

We see the whole migrating population being physically mixed by turbulent diffusion high into the air and descending with variable frequency: and those finding the right place as belonging to this multitude. This section describes the events in the upper air from this point of view.

Aphids are weak fliers: they become dispersed vertically and

laterally by very slight breezes. Where aphids are ubiquitous it is difficult, if not impossible at present, to follow their lateral displacement except over the sea or desert (Elton, 1925; Hardy & Milne, 1937; Wadley, 1931) or to obtain the decrease of density on distance from the source. However, many problems of aerial drift can be studied through the vertical dispersal. Other workers had shown that there is, in general, a decrease of density with height (Hardy & Milne, 1938; Glick, 1939; Freeman, 1945). But their attempts to correlate the number at any height with weather made little progress, for they did not distinguish the three elements determining it, namely population, activity and the distributive process caused by atmospheric circulation. Some features of the first two have been described in the previous section. We will now consider the distributive process irrespective of total numbers involved.

In order to measure the vertical gradient of aphid density and its changes it was necessary to trap at several heights simultaneously up to at least 1,000 feet. The trapping periods had to be short (about an hour at the most), consecutive and continuous during day and night through the whole season. Weather records at different heights were also necessary. This has been achieved with traps and meteorological instruments on a barrage-balloon cable at Cardington.

A convenient, though approximate, procedure with the data is to plot log aphid density (D) on log height (H). This gives a graph which can be regarded as linear for the present analysis. The gradient—that is the general distribution right up through the atmosphere—is then expressed as a single parameter, the regression coefficient b of log D on log H.

When the graph is steep and b is large, relatively more insects are in the lower atmosphere: this suggests less mixing than when b is small and there are relatively more aloft, though other factors, such as rates of supply and deposition, enter the picture.

By integrating this curve the total number of insects in any zone of the atmosphere or in the whole atmosphere can be estimated.

The change in gradient during the day

Flight starts early in the morning, and within the hour insects often reach great heights, where aerial populations usually continue to exist all day. By night-fall, however, as we have shown, there is a general decrease in total number of insects in the air (i.e., the integrated gradient) and the air is usually clear of aphids by day-break. This has sometimes been taken to mean that the insects are precipitated at night, the same individuals having flown about all day; this, however, is not so. It is more rational and in accordance with observations to think of a continual replenishment from plants, a continual mixing up to hundreds or thousands of feet and a continual return of insects to the earth after a relatively short period aloft during the day; so that when mixing and replenishment die out towards evening the downward component dominates and the air clears.

If the atmosphere becomes stable, extremely rapid clearances of aphids from the upper air have been observed even during the day; so that within an hour or two higher altitude densities are too low to be measured. At the same time the fall of temperature with height (the lapse rate) becomes less. It is not known yet how far

this is a general occurrence nor how the decrease of lapse rates are related quantitatively to the concentration of aphids at least into the lower air layers if not to earth. But it does suggest one explanation for the sudden, but quite common, appearance of swarms of aphids.

The double peak of density at crop level is often reflected in a double peak of total aerial numbers (the integrated gradient). This suggests that flight is then rather limited in duration to something less than the duration of a density peak—i.e., about 4 hours—and that on those occasions the first flight makes a major contribution to the daily numbers flying. But again the frequency of this pattern has yet to be measured before we can say how general it is.

However, though the aerial population in general descends by night-fall, it is common to observe extremely low densities high in the sky, and these may persist through the night and add up to a vast number of insects; and though the majority of the day fliers may sometimes travel no farther than a wind of 2 or 3 hours' duration will carry them, the low residual densities appear to indicate that a few persistent fliers may travel much farther. This also is now being put on a quantitative basis and in terms of frequency of occurrence.

We think thus of a continuous upward and downward as well as lateral movement, caused by mixing air masses varying in speed and intensity, and causing continual elevation and descent (sometimes to the earth) of variable numbers of aphids during the daytime; and that it is on some of these aphids, not on a few which escape this process, that the future of the race depends. Low-altitude concentrations or the chances of repeated ascents depend not only on the flight behaviour of the aphids but on atmospheric stability.

Variation in the gradient during the season

1948 was an exceptionally good season; the gradient was measured in 2-hourly intervals during the day and showed a strong seasonal trend. Low values occurred in spring and summer, suggesting maximal upward transport, with about 80 per cent of the aphids commonly above 100 feet; very high values of b with massive low-level concentrations occurred in September and October—with about 80 per cent usually below 100 feet. Summer appeared to be a time of high-altitude dispersal, autumn of low altitude and perhaps more local spread. How is this associated with meteorology?

In general, temperature decreases with height, and the greater the difference the less stable is the air. In 1948 the summer, which was characterized by weak aphid gradients (much upward transport), also had high lapse rate (atmospheric instability) and the autumn, with its strong aphid gradients, by low lapse rates. Thus correlation of gradients with air stability during the day (see above) is paralleled by a similar situation during the season, though how general this is has yet to be discovered.

Expression of the gradient

It is possible to express the vertical gradient for aphids (and for many other insects too) very precisely with an empirical equation. Further, collaboration with Mr. J. G. Skellam of the Nature Conservancy, has put this on a rational basis conforming to a mathematical model of diffusion. This work is being related to that

published previously (C. G. Johnson & Penman, 1951) and will, it is expected, enable gradient problems to be handled with greater ease and precision. It is hoped, too, that the parameters can eventually be resolved into meteorological and biological components.

Some Aspects of Individual Flight Behaviour

The work on the vertical distribution of aphids has been described in general terms: a consideration of individual species of aphids is in progress. Moreover, it has been considered from the collective aspect, and this has its limitations—e.g., an aerial *population* can persist during the day, though the individuals which compose it may be constantly changing. A persistent aerial population does not imply persistent flight; for it it may be composed of different individuals, some taking off as others alight. It is necessary therefore to consider the flight of individual aphids, and especially the factors influencing its character and duration, and the ability of aphids to take-off repeatedly after the first alighting.

During the last three years much work has been done, especially by Bruce Johnson, on the relation between flight activity and host selection; and on the behaviour of aphids after flight. New and interesting lines of work have been opened, and it is impossible to do them justice in this space.

Aphis fabae taking off for the first time frequently flies more or less upwards, usually until out of sight; this behaviour is probably common with many species, though little appears to have been published on it. So strong an upward flight does not appear to be the rule after some subsequent take-offs, though this needs investigation. Although usually attributed to phototaxis, convection currents (which need be very gentle), the flight attitude and wing-beat character may at times influence upward flight, apart from the effects of light. Aphids thus, at least on the first flight and probably on subsequent ones too, usually reach regions where they are carried by the wind.

The mean and maximum duration of flight, and hence the frequency of different distances traversed, are unknown for any species. As suggested on p. 196, the majority of aphids in the air on many occasions are probably limited by air conditions or their own capacity to a flight of something much less than 4 hours, though a small proportion may exceed this. Duration and proportion will no doubt vary greatly, and will no doubt be affected by temperature, humidity and light intensity.

Tethered flight of new aphids on pins, of up to 8–12 hours with some species (C. G. Johnson, 1954), cannot safely be taken as indicating the duration of first flights in nature. For apart from the possibility of abnormal stimulation (B. Johnson, 1955) preliminary experiments with flying aphids on a counterpoise indicate that, though the wings may continue to vibrate, the amount of lift necessary to support the weight of the aphid in free flight diminishes, often within the hour. The problem of flight duration and distance in nature is extremely difficult to analyse; for individuals cannot be followed and the duration of populations in the air is not a guide to the duration of individual flight (p. 195).

Nevertheless, prolonged journeys of hundreds of miles out to sea

have been recorded (p. 196), which indicate that some individuals remain, if not in full and continuous flight, airborne for many hours. The 800 miles recorded by Elton (1927) for spruce aphids could, according to the numbers he saw, have been made by populations in very low densities comparable to those " residual densities " often seen at high altitude overnight at Cardington, a persistent whisp, so to speak, of the main migration.

Eventually the aphids return to the lower air (*Befallsflug* of Moericke (1955*a*) and Müller & Unger, 1952). It is possible, though not proved to be usual, that the aphids often seen flying about more or less horizontally, at crop level or slightly higher, in calm weather have recently experienced a fairly prolonged flight (pp. 195–6).

Eventually they settle on plants staying for periods from a few seconds to an hour or more or even permanently : during this time, even if it is short, they may probe, feed or even deposit young. Or they may do none of these things, but fly off again. This variation in behaviour in relation to flight is a major problem today.

Yellow tray traps 2 or 3 feet above ground level and away from a primary source of alate supply often show the double peak of numbers caught during the day. This has been interpreted by Moericke (1955*a*) and Müller & Unger (1952) as variation on " alighting flight " induced by weather factors. There is no doubt that aphids flying in the lowest air layers are affected by weather: and that different species show a vertical stratification at times (Broadbent, 1948; Müller & Unger, 1952). But the assessment of individual behaviour with instruments which also measure population changes is a risky procedure (p. 194), especially when the instrument itself exerts such an effect on flight (Moericke, 1955*b*; Eastop, 1955).

Flight itself appears to be more than a mere method of transport : Bruce Johnson (1954) has shown that flight, under experimental conditions and possibly also in nature, is a necessary precursor to a change in behaviour leading to acceptance of a plant. Thus the plant on which the aphid is bred is unacceptable to a new alate aphid (Moericke, 1955*a*, B. Johnson, 1954), and aphids in general prefer young and senescent leaves to mature ones; indeed, host choice may be more a matter of leaf age than of difference in plant species (Kennedy, Ibbotson & Booth, 1950; Kennedy & Booth, 1951). For example, if a new *A. fabae* is allowed a very short first flight of about 20 seconds duration it will accept a plant which before the flight it would reject. The more prolonged the flight, the wider the range of maturity in leaves will the aphid accept, and the longer it will stay on a leaf (B. Johnson, 1955).

It is possible therefore that the acceptability in this respect may be changed by the duration of flight in nature and that aphids descending, e.g., at the end of the day, or at night after a flight, especially if in low light intensity, may accept a wider range of hosts, and even refuel on non-host plants, than they would during the daytime or after short flights. This may have important effects. For the acceptance of a host long enough for young to be deposited marks a turning point in the life of many aphid species. After parturition, in some species the flight muscles are autolysed, the capacity to fly disappearing after a few days; in others autolysis begins before parturition (B. Johnson, 1954). In still other species

the flight muscles do not autolyse and the insects are able to fly during several weeks (Haine, 1955).

Thus the acceptability of a host and the flying life of an aphid is intimately associated with the act of flight. There is evidence, however, that the stimulation of handling in the laboratory also affects the relation of flight to host choice and that in nature the effects of flight may be somewhat different from the description given above. Nevertheless, it is clear that host selection and activity, whether by flight or other forms of stimulation, are closely linked.

The acceptability of a host and the state of the aphid and the conditions of light and weather decide if the aphid will make repeated flights from plant to plant once in their vicinity; but little is known of this in the field. How long this kind of flight can continue is conjectural: B. Johnson (1955) produced evidence that the total flight capacity may be lengthened by repeated feeding between flights, and bean aphids are known to visit different plants repeatedly in nature (Müller, 1953). *Myzus persicae* is notoriously restless in this way, and other species deposit young and fly away. Aphids pass out of the accepting state and then require more flight before regaining it (B. Johnson, 1955). Neither is it known if the quality of flight is changed in the early stages of muscle autolysis. These aspects of flight, especially the mechanism of repeated host visitation, are of direct significance to understanding how aphids spread viruses and perhaps why some are more important pests than others. Most work has, however, been done with *A. fabae*, and other species need study along similar lines.

Thus such questions as " How long does an aphid fly? " or " How far does it travel? " cannot be answered simply. Neither can such questions be answered comprehensively unless in collective terms as well as in those of individual behaviour. For to variation on the part of an individual at different times is added the variation between different individuals: and for ecological and epidemiological purposes the questions should be reframed thus: " What is the variation in flight duration between different individuals and what proportion of these fly for the different times? " " What proportion of aphids reach varying distances from a source? " So, in questions of aerial distributions we must ask " What proportion of an aerial population returns to earth (or near it), once, twice, three times, etc. in a given period during the day? " These questions cannot yet be answered precisely; but we are proceeding in the direction, in terms of the individual and of the crowd, which I think will enable answers to be given.

Dispersal and the Control of Bean Aphis

A very moderate infestation of *A. fabae* has a serious effect on the yield of field beans: by the time colonies are obvious without close inspection, much damage may be done (Judenko, C. G. Johnson & Taylor, 1952). Moreover, the greatest rate of population increase occurs in the early stages of infestation before colonies are very large (unpublished data).

It is therefore rational to begin control measures before the infestation becomes obvious to a superficial inspection: that is, as soon as the migration has ended (C. G. Johnson (part author), 1952),

or with a persistent insecticide before this. Spectacular contro has been carried out along these lines by Way, Smith & Potter (1954).

The duration of migration is itself very variable, and may occupy 1 week or 4 or 5 weeks in different years : and with the known effect of wind on dispersal and the commonly observed " edge infestations " on beans it was worthwhile to attempt to correlate wind direction with infestation pattern (C. G. Johnson, 1950; Taylor & C. G. Johnson, 1954). We found that often the windward edges bore a heavier deposition of migrants; and often also a heavier colony growth which it is plausible to suppose was due to the delivery of more migrants on the windward side. But there are sometimes more colonies near trees and hedges irrespective of wind direction and number of migrants deposited. We have found recently that very small temperature rises above the developmental threshold, especially between 16° and 21° C., increase the rate of development by more than twice compared with a similar temperature rise above 21° C. : it now appears to be worth while to study the rate of colony growth in relation to microclimates in sheltered compared with exposed places in the crop as well as to deposition of migrants.

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THE HATCHING OF CYST-FORMING NEMATODES

By

D. W. Fenwick

The genus *Heterodera* contains a number of species of cyst-forming plant-parasitic nematodes. They are highly specialized morphologically and biologically, and one of their adaptations to parasitism is their selective response to substances which are produced by the roots of host plants and which are generally referred to as root diffusates. Before considering the work of the Nematology Department on this subject it is opportune to summarize the life history of a typical member of this genus. Soil infested with *Heterodera* spp. contains round or lemon-shaped bodies known as cysts about $\frac{1}{2}$ mm. in diameter and brown in colour; these cysts may contain up to 700 eggs, each of which may contain a larva. In the absence of host plants larvae emerge only slowly—in the case of the potato-root eelworm *Heterodera rostochiensis* Woll. about 40–50 per cent in one year; the cysts can therefore remain infestive for several years. When a host plant is present diffusates produced by the growing roots stimulate the larvae to emerge rapidly—with the potato-root eelworm up to 80 per cent of the contained larvae emerge from cysts in the vicinity of plant roots in the first few weeks of the plant's life. Following penetration of the roots, development of the larvae results in the production of a new generation of flask-shaped females which protrude from the roots as white, rounded bodies containing large numbers of eggs. They lose their white colour and become brown, the body hardens and dies, the dead body acts as a protective envelope for the viable eggs and later becomes detached from the roots to lie freely in the soil. This is the cyst stage referred to above.

Hatching from beet-eelworm cysts (*Heterodera schachtii* Schmidt) was shown by early German workers to be stimulated by diffusates produced by the roots of host plants. Triffitt (1930) investigated this in detail. Working with *H. rostochiensis*, she concluded that potato roots would produce a diffusate capable of stimulating larval emergence only as long as root growth was actively occurring; the stimulatory factor was heat resistant and active in high dilutions; its breakdown was rapid under non-sterile conditions. Triffitt also confirmed the findings of Morgan (1925) that the diffusate from mustard roots was antagonistic to potato-root diffusate and did not stimulate potato-root eelworm; the substance was present in shoots and, unlike potato diffusate, was comparatively stable under non-sterile conditions. She also reported a dormancy period during the winter when larval emergence was extremely slow. In later papers (1932, 1934) Triffitt presented data showing that certain grasses produced diffusates which stimulated the hatching of potato-root eelworm. Franklin (1937) detected the same effects with diffusates of white mustard and yellow maize.

Our present understanding of the problem throws considerable doubt on the reliability of a great deal of this work, which was based on the assumption, now known to be erroneous, that all cyst-forming species of *Heterodera* were biological strains of *Heterodera schachtii*; the very high level of variability exhibited by eelworm cysts, and the absence of sound statistical design, make it difficult to assess the validity of the findings. The main conclusions to be drawn appear to be that root diffusates can induce the emergence of larvae from cysts; their action is specific, i.e., a given species of eelworms can only be stimulated by diffusates from certain plants.

Work carried out in the Nematology Department on larval emergence of *Heterodera rostochiensis* can conveniently be divided into three main sections:

(*a*) The development of satisfactory techniques for the conduct of hatching tests.

(*b*) An examination of the factors influencing hatching in the laboratory and in the field.

(*c*) An attempt to elucidate the chemical nature of the active principle in potato-root diffusate.

Techniques

When hatching tests were commenced it was found that a number of factors rendered their conduct very difficult: the number of eggs per cyst within any population was very variable, which resulted in tests being subject to large and unpredictable errors: cysts from different populations differed considerably, both in egg content and also in their response to hatching stimuli, so that it was difficult to obtain results capable of generalized application. Nothing was known about the "quality" of the diffusate used, since the method for its collection was not amenable to rigid control, and the chemical constitution of the active factor was unknown.

Preliminary investigations involved isolating the larvae hatched from single cysts, for this a new slide was designed (Fenwick, 1943) as a refinement of the single-cyst techniques of Gemmell (1940) and Ellenby (1943). Using this slide, 50 cysts could be accommodated individually in glass cups on a 6 × 6-cm. glass plate. Using cysts from a number of populations and exposing them individually to diffusate drawn from a single bulk stock, it was possible to investigate the variability exhibited within and between different populations. The results of these investigations (Fenwick, 1949) showed that if batches of 100 cysts were used as units in hatching tests a basic minimum error of ±10 per cent was to be expected.

The use of units of this magnitude introduced new problems of technique, the most important of which was the counting of the thousands of larvae produced. Two modifications (Fenwick, 1951*c*; Peters, 1952) of the McMaster slide (Gordon & Whitlock, 1939) enabled this to be done by dilution. To overcome the tedium and labour in setting up replicate batches of cysts, a weighing technique (Fenwick & Reid, 1952) and later a sucking technique (Hesling, 1952) were developed. The use of either of these methods in conjunction with the mechanical purification methods developed by Hesling (as yet unpublished) have made it possible to conduct

hatching tests on a larger scale than could previously have been contemplated.

The investigations of Elizabeth Reid (afterwards Widdowson) into problems of production and storage of root diffusates have led to a more standard and reliable product which can be preserved for several months with little loss of activity.

A difficulty associated with hatching tests has been the fact that larval emergence in the laboratory is a protracted business occupying up to 3 or 4 months. Preliminary investigations into the form of the hatching curve (Fenwick, 1950*a*) showed it to be sigmoidal in character when hatch was plotted against log time. Use was made of this relationship to forecast, at the end of 10–12 days, what the final hatch would be (Fenwick, 1951*b*). Although this shortened the total duration of a test, the need for daily counts during this period increased rather than decreased the total labour required on a test. Later work has shown this labour to be unnecessary, and it is now standard practice to run a test for 21 days, the hatched larvae being counted at 7 and 21 days. By this method 85 per cent of the hatchable larvae are recovered.

In any hatching tests, two classes of larvae are recognizable—those which hatch and those which do not. The former are counted when they emerge, but the latter are frequently of equal importance, and it is often necessary to estimate them quantitatively. Two techniques for estimating the unhatched larval content of cysts have been developed (Reid, 1952 and 1955) and are of great importance in potato-root eelworm research; they form the basis of the egg-hatching experiments referred to later, and are in general use for infestivity investigations outside Rothamsted.

As a result of the development of the above techniques it has been possible to lay down standard hatching procedures giving results of predictable accuracy: even so, a very high degree of replication is necessary if a reasonable degree of precision is to be obtained. In hatching tests conducted by the writer over several years, using weighed batches of 150–200 cysts in five-fold replication, the overall errors have been of the order of ± 20 per cent. This has been shown to be due, primarily, to the variability in the egg content of individual cysts. A new technique has been developed in which eggs, after removal from the cysts, are exposed to the action of diffusates. There is every reason to believe that the errors resulting from cyst variability can be significantly reduced by this method, with a substantial saving in material and effort.

The " dormancy period " experienced by Triffitt, when hatching was very slow, has been investigated, and techniques have been described (Fenwick & Reid, 1953) for the storage of cysts, which have enabled hatching tests to be conducted throughout the year, with no apparent diminution of hatching in winter.

The techniques so far described have all been concerned with measuring and reducing the errors resulting from the variability in egg content of *Heterodera* cysts. Variations in potency of natural diffusates are of equal importance, and a technique has been developed for standardizing a given sample (Fenwick, 1952*b*). If a sample of diffusate be diluted in a logarithmic series, larval emergence in each successive sample decreases in a linear manner. It was found possible, by plotting a curve, to calculate a

" threshold " value of concentration beyond which a sample of diffusate was inactive. A strength of 1 arbitrary unit of concentration was ascribed to this " threshold ", and original concentration was expressed in terms of it—i.e., if the " threshold " for a sample corresponded to a 1/1,000 dilution, then the strength of the original sample was 1,000 arbitrary units. In practice a new term was used—the L.A. value (the logarithm of the concentration of the hatching factor)—which was proportional to the hatching ability of a given sample of diffusate. Using this technique, it has been possible to secure by dilution diffusates of known L.A. values and to measure quantitatively root-diffusate production and breakdown.

All the experiments so far described have been carried out on apparently " normal " cysts as recovered from naturally infested soil, i.e., they have not been treated with nematicidal fumigants. As far as the writer is aware, the relatonships so far mentioned in this review have never been tested on cysts exposed to nematicides. This point is worthy of emphasis, since many workers have sought to utilize hatching responses as a method of estimating kill following nematicidal treatment. In the absence of data showing the effect of chemical pretreatment on the parameters of the hatching dilution curves, interpretation of these workers' data is at most conjectural. Even if the same or new relationships for hatching can be applied to cysts treated with nematicides, the " hatchability " of larvae may not be synonymous with their " viability ". To regard the results of hatching tests as more than a mere indication of viability is an unjustified assumption. A thorough investigation into the relationship of hatchability to viability is an essential preliminary to the use of hatching tests in nematicidal work.

Larval emergence in the laboratory and in the field

Diffusate for hatching tests on *H. rostochiensis* is usually obtained from potatoes grown in 6-inch pots of 3 : 1 loam and sand, and knowledge is now available of some of the factors influencing its production. Elizabeth Reid has carried out experiments on the relationship of the age and variety of potato and tomato plants on root-diffusate production, and has investigated the effect of infestation with potato-root eelworm on root-diffusate production. Her work indicates that root-diffusate production is closely correlated with rate of increase of root growth measured by weight : total root weight plays a subsidiary but significant part. In the case of potatoes, diffusate production is at a maximum 5–6 weeks after planting, and this is the period of maximum rate of growth under experimental conditions. A large number of potato varieties has been tested, but there is little evidence of marked differences in the potency of the diffusates produced. Comparisons between potatoes and tomatoes showed that in the early stages of growth, diffusates from the latter were less active, but in older plants diffusate production in both was comparable; as potatoes require less attention than tomatoes, they are more suitable plants for root-diffusate production. Increased root-diffusate production resulted when potatoes were exposed to a low to medium rate of infestation with eelworm, which stimulated root proliferation. Heavy attacks stunted root growth and reduced the production of diffusate. Root-diffusate production appeared to be a function of growth. Elizabeth

Reid has shown that root diffusate is produced equally well in soil, in sand with the addition of a plant nutrient or in sand watered only with distilled water; in the last case, however, production was not maintained for so long.

Root-diffusate production by plants other than potatoes and tomatoes has received attention. J. J. Hesling has repeated the work of Triffitt and of Franklin on the effects on *H. rostochiensis* of root diffusates of Gramineae. Fourteen species of grasses and five varieties of cereals were tested. Diffusates collected after three weeks growth did not stimulate the hatching of *H. rostochiensis*. He also compared diffusates produced by *Solanum andigenum* Juz. and Buk., *Solanum demissum* Lindl. and potato. All three species produced active diffusates, but as no account was taken of root size or growth rates comparisons among them were difficult.

Investigations by C. C. Doncaster showed that the nightshade *Solanum nigrum* L., which is not a host of potato-root eelworm, although it can be invaded, produced a very active diffusate. In the presence of even light infestations, diffusate production in young plants was reduced, but this effect was not so marked with older plants. Experiments on trap-cropping with this plant gave disappointing results.

Doncaster (1955) has also worked on the hatching responses of *Heterodera cruciferae* Franklin by diffusates produced by sprouts, swedes, rape kale and mustard. They are all active, although mustard is less so than the other three. There is no evidence that the addition of mustard diffusate to the others has any inhibitory effect. He finds that the hatching curves for these diffusates are sigmoidal and that their dilution curves are similar to those for potato-root diffusate.

Attempts by J. J. Hesling to obtain a diffusate which stimulates the hatching of *Heterodera major* (O. Schmidt) have been unsuccessful.

Experiments on the factors influencing the hatching of *H. rostochiensis* in the laboratory have been carried out (Fenwick, 1951*a*). Presoaking of dry cysts for 7–12 days in tap water before exposure to root diffusate increases the rate of hatching, but has no effect on the total number of larvae emerging from replicate batches of cysts. A constant temperature of 25° C. appears to be the optimum, but 30° C. inhibits hatching. Within wide limits larval emergence is not influenced by the volume of diffusate used nor by the number of cysts in that volume. Direct sunlight inhibits hatching, and this effect is permanent; cysts having been exposed to it, still do not hatch when transferred to the dark; diffused light is without effect. Hatching is unaffected by pH between 3·2 and 8·1. Hesling has found that if cysts of different sizes are exposed to potato-root diffusate there is a tendency for larvae to emerge from smaller cysts more readily than from the larger.

The hatch in water varies between the different species of *Heterodera*. In *H. rostochiensis* emergence is very low, but considerable spontaneous hatching can occur in the case of *H. cruciferae*, *H. trifolii* and *H. schachtii*; *H. göttingiana* and *H. major* do not normally hatch in water. The hatching of *H. major* has been investigated by Hesling, who found that it occurred in spring and summer as a result of a rise in temperature, the effect of which lasted

6–10 days. Hatching from the cysts of *H. major* was inhibited by drying. When cysts were exposed to different relative humidities he found that those exposed to R.H. 98–100 per cent "hatched" equally well as cysts which had not been dried. Exposure to R.H. 87 per cent and lower inhibited hatching for a considerable time.

Larval emergence in soil and sand has not been investigated in such detail as it has in fluid media. J. J. Hesling found that hatching of *H. rostochiensis* in sand saturated with root diffusate was very similar to that observed in watch-glasses—the hatching curve was sigmoidal and its parameters did not differ substantially from those in fluid media. Other work on this subject has been done by Elizabeth Reid. She used shallow seed pans 12 inches in diameter filled with damp sand which had been uniformly infested with potato-root eelworm cysts. Known volumes of root diffusate were added to the centre of each pan twice daily for 8 weeks. After this time the larval content of cysts near the application point had fallen by 80 per cent, compared with a fall of 40 per cent near the perimeter.

Fenwick (1950*b*) investigated the effect of root diffusates from different varieties of potatoes in natural infestations of cysts on three different soils. In the absence of diffusate larval emergence over a season was about 50 per cent: in the presence of diffusate, 84 per cent of the larvae emerged. There was evidence of differences in response to diffusates from different varieties of potato and in the response of cysts from different localities to a single diffusate.

Hatching of *H. major* in soil under natural conditions has been shown by Hesling to occur at a steady rate from March to July during which time about 50 per cent of the cyst contents emerge. After July, hatching is considerably reduced.

Interesting results have been obtained by comparing hatching from free eggs of *H. rostochiensis* with eggs within their cysts. The general relationships were similar in both cases: the hatching curve was sigmoidal and the dilution curve was linear, although in general the rate was slightly faster in the case of free egg hatching. An interesting effect has been observed as a result of presoaking experiments. Eggs from cysts presoaked in water for 7 days hatched faster in root diffusate than those from dry cysts. If eggs from dry cysts were soaked, soaking appeared to inhibit subsequent hatching. This was the case whether particles of cyst wall were present during soaking or not—merely squashing cysts before soaking was sufficient to inhibit hatching of eggs. Soaking of whole cysts for as little as 1 hour counteracted this effect. No convincing hypothesis has been advanced to explain this curious result.

A factor which must influence larval emergence in soil is the degree of persistence of diffusate. The stability of potato-root diffusate under storage conditions has been investigated by Elizabeth Reid: she has confirmed Triffitt's findings that at room temperature it breaks down fairly rapidly; at 0–5° C. no appreciable loss in activity occurs over 12 months.

Fenwick has investigated its breakdown in soil. In a naturally infested heavy loam, breakdown was very rapid—90 per cent of the active principle was lost in 4–6 days, and the effect of a single application on the egg content of cysts was very small. When root diffusate was applied to horticultural peat, clay, sand and

gravel its breakdown in peat was less rapid than in the other three media. When repeated applications of root diffusate were made to soil the breakdown of later applications was more rapid than of the earlier. Breakdown in partially sterlized soil was less rapid than in unsterilized soil. The author believes that in soil, breakdown is due to the action of micro-organisms which utilise root diffusate as a substrate. The results of these experiments cast considerable doubt on the practicability of using root diffusate as a method of eelworm control; it would appear unlikely that root diffusate can persist in soil long enough to have any appreciable effect in causing larvae to hatch in the absence of a host plant.

Chemical investigations

In 1951 a project for research into the chemical nature of the potato-root eelworm hatching factor was financed by the Agricultural Research Council to be carried out jointly at Reading, Cambridge and Rothamsted. At Reading, Professor R. H. Stoughton grew potatoes in order to produce the active diffusate; at Cambridge, Professor Sir A. R. Todd and his collaborators worked on the analysis of the active principle; at Rothamsted, the Nematology Department undertook the assay of "fractions" produced at Cambridge.

Preliminary isolation of the factor (Johnson, 1952) was accomplished by adsorption of the active principle from crude leachates on animal charcoal which was subsequently eluted with aqueous acetone. The hatching factor was found to be relatively stable between pH 2 and 7, but was rapidly deactivated at pH 8 and over. It was acidic, of low molecular weight and probably contained a lactone group. Treatment of the active brucine salt with acid followed by exaustive extraction with ether gave an acidic resin, active at concentrations of 1×10^{-7} to 1×10^{-8} and the name "eclepic acid" was proposed. Because of the heavy losses of active principle involved in this process, physical methods of purification were examined. Extraction of the crude concentrate with ether proved useful, as also did partition chromatography in silica gel buffered at pH 6. Titration of the product indicated an equivalent of 250–290; there was evidence of at least one double bond in the compound, and an approximate formula of $C_{19}H_{26}O_8$ was proposed.

Armitage (1955) attempted concentration by vacuum distillation. Phenol extraction of the product resulted in negligible recovery of the active principle. He then resorted to ion-exchange techniques. After preliminary passage through a cation-exchange resin (Zeokarb 225) the activity was retained on an anion-exchange column (Deacidite FF) and recovered from this by elution with 3*N*–HCl: the product had considerable activity, but phenol extraction of it resulted in considerable losses. Paper-strip chromatography of the organic acid fraction using a *n*-butanol–water–formic acid developer disclosed six acids. All attempts to obtain a solid derivative failed, as also did attempts to separate the water-soluble organic acids, whether by counter-current distribution, ion-exchange chromatography or partition chromatography.

After Armitage's departure from Cambridge in August 1955 the

joint work with Cambridge and Reading ceased, but a series of joint small-scale experiments was commenced by D. W. Fenwick and G. N. Wiltshire at Rothamsted. As a result of cation exchange by charcoal adsorption and acetone elution, these workers reduced the dry weight of substances to 0·5 per cent of the original, with only a small loss of the active factor; this corresponded to a purification factor of ×184. Further work on this is in progress, but is not as yet far enough advanced for comment.

This review is a summary of the work carried out in the Nematology Department, Rothamsted. Valuable research is being carried on at several other centres, but there is not space to describe them in this review.

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PUBLICATIONS

Physics Department

Book

1. Penman, H. L. (1955). *Humidity*. London: The Institute of Physics.

General Papers

2. Long, I. F. (1955). Dew and guttation. *Weather*, **10**, 128.

3. Long, I. F. (1955). Frozen dew. *Weather*, **10**, 199.

4. Penman, H. L. (1955). Water control for increased crop production. *Advanc. Sci., Lond.*, **12**, 29.

5. Penman, H. L. (1956). Evaporation: an introductory survey. *Neth. J. agric. Sci.* (In the press.)

Research Papers

6. Emerson, W. W. (1955). Complex formation between montmorillonite and high polymers. *Nature, Lond.*, **176**, 461.

7. Emerson, W. W. (1956). Synthetic soil conditioners. *J. agric. Sci.*, **47**, 117.

The ability of various high polymers to stabilize soil crumbs has been investigated using the sodium saturation technique. The soil used came from two plots on the Rothamsted classical fields, Barnfield and Hoosfield, which have received no fertilizer, either organic or inorganic, for 80 years, but whereas the former contains free $CaCO_3$, the latter is acid. The polymers tested were polyvinyl alcohol, sodium alginate, a vinyl acetate–maleic acid co-polymer, polyacrylic acid and a dextran. It was necessary to add 0·2–0·5 per cent weight of the polymers in solution to the calcareous soil to produce crumbs of maximum stability, i.e., not dispersing in distilled water. The alginate, however, was effective only if the crumbs were first sodium saturated. With the acid soil, the amount of polyvinyl alcohol necessary for maximum stability was slightly reduced corresponding to the lower clay content of the soil, whereas only one-tenth the concentration of the maleic acid co-polymer was required. Sodium alginate had no effect on the acid soil.

From the swelling pattern of the Na-saturated crumbs in dilute salt solutions it was inferred that the non-ionic polymers, polyvinyl alcohol and the dextran form inter-lamellar complexes, whereas the carboxylated polymers are joined to the edge faces of the crystals. The presence of divalent cations is unnecessary for this edge linkage, as the polymers are equally effective when sodium ions only are present. It is suggested that the polymers form a series of hydrogen bonds with the exposed oxygen and hydroxyl atoms of the octahedral layer. Since these atoms have a greater tendency to co-ordinate a hydrogen ion as the pH is lowered, the carboxylated polymers would be expected to be more efficient on acid soils.

A simplification of the sodium saturation technique for the evaluation of potential soil conditioners is given.

8. Emerson, W. W. (1956). A comparison between the mode of action of organic matter and synthetic soil conditioners in stabilizing soil crumbs. *J. agric. Sci.* (In the press.)

Synthetic soil crumbs stabilized by the addition of small quantities of a polymer, and natural soil crumbs from old grassland, have been extracted with neutral sodium pyrophosphate and alkali and the strengths of the crumbs compared before and after extraction, using the sodium saturation technique. Three polymers were used: polyvinyl alcohol (a non-ionic polymer), sodium

alginate and a vinyl acetate–maleic anhydride co-polymer (Vama), the latter both carboxylated polymers. Pyrophosphate was able to displace the carboxylated polymers from the synthetic crumbs, but not the stabilizing fraction of the organic matter from the grassland crumbs. 0·5*N*-NaOH produced a much greater reduction in the strength of the alginated treated crumbs compared with Vama crumbs, which is attributed to the weaker hydrogen bonds formed by the former. Prolonged leaching with alkali removed a considerable part of the stabilizing organic matter in the grassland crumbs. Neither method of extraction affected the stability of the polyvinyl alcohol crumbs.

It is concluded that the grassland crumbs are stabilized by the formation of inter-lamellar complexes with the clay in the crumbs, and probably that the substance forming the complexes is a polymer and contains amino-groups.

Evidence is also given that phosphate ions and the carboxylated polymers are attached in the same manner to the edges of the clay crystals.

9. Long, I. F. (1956). The direct evaluation of psychrometric data from dry- and wet-bulb recorders. *J. Sci. Inst.* **33**. (In the press.)

10. Monteith, J. L. (1956). Evaporation at night. *Neth. J. agric. Sci.* (In the press.)

Direct measurements of evaporation from a short grass surface are compared with humidity gradients in the grass. At night, when the air in the cover is unsaturated, evaporation takes place by the diffusion of water vapour from the soil surface through a thin air layer in which the transfer coefficient is seldom greater than twice the molecular value.

11. Penman, H. L. (1955). Weather and farming, 1954. *Quart. J. R. met. Soc.* **81**, 507.

1954 weather was most marked in its grievous interference with soil management and crop husbandry. Farming skill and energy succeeded in doing much to counteract this, so much so that final yields were generally above average. The weather generally retarded growth and encouraged fungus diseases, so reducing quality. Some of the effects of 1954 weather may appear in 1955 crops.

12. Penman, H. L. (1955). Evaporation from Lake Eyre. In: *Lake Eyre, South Australia. The Great Flooding of 1949–50*, (*Roy. Geog. Soc. Australasia, Adelaide*), pp. 57–61.

Computed values of evaporation, based on weather data for October 1950 to December 1951 give a total of 105 inches for 14 months, ranging from 1·5 inches in June to 13 inches in January 1951. Direct measure (based on some eye observations) totals 120 inches for the same period.

13. Penman, H. L. (1956). Estimating evaporation. *Trans. Amer. geoph. Un.*, **37**, 43.

The physical basis for computing potential transpiration rate from weather data is outlined. Such computations have formed the basis of successful experiments in irrigation control, and with suitable modifications, have been applied with some success in studies of the water balance of catchment areas. Applied to two classical American watershed studies, the treatment suggests that some of the Coweeta results may need reconsideration.

14. Schofield, R. K. & Taylor, A. W. (1955). The measurement of soil pH. *Soil Sci. Soc. Amer. Proc.* **19**, 164.

A number of experimental results are presented which show the variation of the pH values of several soils when samples of each are shaken with $CaCl_2$ solutions of different concentrations.

These results are then interpreted on the basis of the ratio law—derived from the Gouy theory of the electrical double layer—and it is shown that the pH values and electrolyte concentrations show the expected relationship, provided the latter is not too large.

The importance of the connection between pH and electrolyte concentration in the routine measurement of soil pH is emphasized, and it is pointed out that such measurements must be carried out, using an electrolyte solution of known composition in order to obtain comparable results from different soils.

It has been found that 0·01*M*-$CaCl_2$ is the most satisfactory for use in normal non-saline soils where the surface density of electrical charge on the colloidal material is high and independent of the solution composition : this electrolyte concentration is such that measurements made with the usual glass electrode/saturated calomel cell give accurate and reproducible values which are largely independent of the soil/solution ratio, and are yet sufficiently dilute to allow a satisfactory calculation of the " lime potential " characteristic of the soil sample.

Chemistry Department

15. Cooke, G. W. (1954). Recent developments in the use of fertilizers. *Agric. Progr.* **29**, 110.

The changes in fertilizer consumption in the United Kingdom from 1913 to the present time are described. Fertilizer efficiency may be increased by using the results of soil analysis and by applying placement methods. Current fertilizer practice is discussed in relation to the improvements which are possible in manuring under various systems of farming.

16. Cooke, G. W., & Widdowson, F. V. (1955). Fertilizer placement for arable and herbage crops. *Herb. Abstr.* **8**, 233.

A general account of the benefits of fertilizer placement for cereals, row crops, horticultural crops and herbage crops. An account is also given of fertilizer placement research in other European countries.

17. Cooke, G. W. (1955). Field experiments on phosphate fertilizers. *N.A.A.S. quart. Rev.* **27**, 95.

A summary is given of the results of war-time and post-war field experiments, testing alternatives to superphosphate.

When used for direct application, soft North African rock phosphates and phosphate from Curacao in the West Indies behaved similarly, Florida pebble phosphate was inferior to other rock phosphates. For swedes grown on acid soils North African rock phosphates were from 60 to 90 per cent as efficient as superphosphate. For potatoes on acid soils and for establishing reseeded grassland rock phosphates were as effective as only one-third as much phosphorus supplied as superphosphate; on neutral soils they were useless for any of the crops tested.

Silicophosphate behaved like a very high-grade, high-soluble basic slag. It was roughly equal to superphosphate for swedes and potatoes grown on very acid soils. On neutral soils silicophosphate was inferior to superphosphate for all crops.

Dicalcium phosphate was equivalent to superphosphate for swedes grown on all kinds of soil; for potatoes it was slightly superior to superphosphate on very acid soils and slightly inferior on neutral soils.

Three kinds of nitrophosphate, made by treating rock phosphate with nitric acid followed by ammoniation, were compared with superphosphate. The phosphorus in all three products was equivalent to phosphorus in superphosphate for swedes. The nitrophosphates were inferior to equivalent mixtures of superphosphate plus nitrogen fertilizers for potatoes and for grass; they tended to be more effective on acid soils than on neutral soils. In the different years of the experiments the same kinds of nitrophosphates gave variable results. It appeared that the manufacturing processes needed further investigation so that stabilized products with consistent performances could be marketed.

18. Cooke, G. W. (1955). Make good what the rain washed out. *Fmr & Stk-Breed.* 15 February, p. 55.

An article for farmers. The factors which must be taken into account in planning manuring with nitrogen and potassium are discussed.

19. Cooke, G. W. (1955). Making the best use of fertilizers. *Times Agric. Rev.* Spring 1955, 20.

An account of the purposes for which fertilizers are applied in the United Kingdom. Methods of improving the efficiency of manuring are described.

20. Cooke, G. W. (1955). Alternatives to superphosphate. *Agriculture, Lond.* **62**, 27.

Tests with various phosphates have been carried out both during and since the war in an attempt to find a substitute for superphosphate which will not make such heavy demands on sulphuric acid in its manufacture. The results of the work are described.

21. Cooke, G. W. (1955). A summary of the results of fertilizer placement research in Great Britain. *Bull. Docum. Assoc. int. Fabr. Superph.* **18**, 16.

A summary in French and English of recent work.

22. Widdowson, F. V. (1955). Precision is the aim and placement is the method. *Agric. Rev. Lond.* **1**, no. 5, 40.

The advantages and disadvantages of various methods of applying fertilizer for common farm crops are described.

Research Papers

23. Benzian, B. (1955). Nutrition problems in forest nurseries. Summary report for 1953. *Rep. For. Res. For. Comm. for 1953–54*, 38.

24. Bremner, J. M. (1955). Studies on soil humic acids. I. The chemical nature of humic nitrogen. *J. agric. Sci.* **46**, 247.

The chemical nature of the nitrogen in humic acid preparations isolated from 0·5*M*-sodium hydroxide and 0·1*M*-sodium pyrophosphate (pH 7·0) extracts of nine different soils has been studied by determining the amounts of acid-soluble-N, ammonia-N, amino-sugar-N and α-amino-N liberated by acid hydrolysis of the preparations and by paper chromatographic analysis of their acid hydrolysates. Humic acid preparations isolated from alkali and pyrophosphate extracts of the same soil differ markedly in total nitrogen content and in nitrogen distribution after acid hydrolysis. The alkali-extracted preparations have a higher nitrogen content and a higher proportion of acid-soluble-N and α-amino-N. A considerable fraction (20–60 per cent) of the nitrogen in the preparations examined was not dissolved by acid hydrolysis. The major fraction of the nitrogen dissolved was in the form of amino-acids. At least 31–48 per cent of the nitrogen in the alkali-extracted preparations and 20–35 per cent of the nitrogen in the pyrophosphate-extracted preparations was in the form of protein. From 3 to 10 per cent of the nitrogen in the preparations was in the form of amino-sugars. The results obtained by paper chromatographic analysis of acid hydrolysates of the preparations indicated that the protein materials in humic acids isolated from different soils by alkali or pyrophosphate are similar in their amino-acid composition. The following nineteen amino-acids were detected in every hydrolysate examined : phenylalanine, leucine, *iso*leucine, valine, alanine, glycine, threonine, serine, aspartic acid, glutamic acid, lysine, arginine, histidine, proline, hydroxyproline, α-amino-n-butyric acid, β-alanine, γ-aminobutyric acid and tyrosine. Two unidentified ninhydrin-reacting substances, oxidation products of cystine and methionine, and amino-sugars were also detected in every hydrolysate examined. A third unidentified ninhydrin-reacting substance and a substance provisionally identified as α, ε-diaminopimelic acid were found in some of the hydrolysates.

25. Bremner, J. M. (1955). Nitrogen distribution and amino-acid composition of fractions of a humic acid from a chernozem soil (Hildesheimer Schwarzerde). *Z. PflErnähr. Düng.* **71**, 63.

The nitrogen distribution and amino-acid composition of the B_a and G_a fractions obtained by fractionation of a humic acid from a chernozem soil with alkali have been investigated. The fractions were found to differ markedly in nitrogen distribution, the B_a fraction having a much higher proportion of its nitrogen in the form of acid-soluble- and α-amino-nitrogen. No marked difference in the amino-acid composition of the two fractions was revealed by paper chromatographic examination of their acid hydrolysates.

26. Bremner, J. M., (Flaig, W. & Küster, E.) (1955). Zur Kenntnis der Huminsäuren. IX. Mitteilung. Der Gehalt an Aminosäuren in Streptomyceten-Huminsäuren. *Z. PflErnähr. Düng.* **71**, 58.

The amino-acid composition of a humic acid-like substance produced by a streptomycete was found to differ from that of soil humic acids, particularly in tyrosine content. The amino-acid composition of streptomycete mycelium appears to be fairly constant qualitatively and little affected by the type of nitrogen supplied for growth.

27. Bremner, J. M. & Shaw, K. (1955). Determination of ammonia and nitrate in soil. *J. agric. Sci.* **46**, 320.

Methods for the determination of ammonia and nitrate in soil are described. The ammonia and nitrate are extracted at pH 1·0–1·5 with a mixture of potassium sulphate and sulphuric acid, and the ammonia is determined by distillation with magnesium oxide at 25° C. in a modified Conway micro-diffusion unit. Ammonia plus nitrate is determined on a separate sample of the same extract by reduction of the nitrate to ammonia with titanous hydroxide and subsequent distillation with magnesium oxide, both the reduction and distillation being carried out in a modified microdiffusion unit at 25° C. The methods are applicable to coloured extracts and are not affected by substances found to interfere with other methods of determining ammonia and nitrate.

28. Bremner, J. M. & Shaw, K. (1955). Reduction of nitrate by ferrous hydroxide under various conditions of alkalinity. *Analyst*, **80**, 626.

An investigation of the reduction of nitrate to ammonia by ferrous hydroxide under various conditions of alkalinity showed that quantitative reduction of nitrate could be obtained by boiling with ferrous sulphate and magnesium oxide. The significance of this finding in relation to the determination of ammonia in soil by Olsen's method is discussed.

29. Cooke, G. W. (1955). The performances of fertilizer distributors used in field experiments. *Emp. J. exp. Agric.* **23**, 244.

The performances of two commercial fertilizer distributors in spreading powdered and granular fertilizers were compared with special reference to the use of such machines in experimental field work.

A combine-drill fitted with a star-wheel mechanism consistently delivered fertilizers more regularly than a " plate-and-flicker " mechanism fitted to a broadcast distributor. Granular fertilizers were delivered more regularly than powders. Both distributors were useless for dispensing a very fine and light powdered fertilizer (dicalcium phosphate) which did not flow by gravity. When such commercial machines are used the initial delivery should be rejected and the hopper should be refilled when three-quarters of the fertilizer has been dispensed.

The star-wheel machine delivered four granular fertilizers at rates which did not vary by more than ± 10 per cent of the average rate; the revolving-plate distributor was equally successful with three of the four granular materials. Both distributors dispensed three powdered fertilizers within these limits of variation.

Likely variations in delivery rate may be estimated by testing the performance of distributors in the field. The effect of such variations on crop yields, and therefore on the accuracy of the experiments, may be estimated by studying the responses of the crops to the fertilizers under test. By setting limits of tolerance in fertilizer delivery rates the suitability of machines for particular purposes may be estimated.

30. Cooke, G. W. & Widdowson, F. V. (1956). The value of nitrophosphate for spring-sown cereals. *J. agric. Sci.* **47**, 112.

Thirteen experiments on spring cereals were carried out from 1952 to 1954 to compare broadcasting with combine-drilling for nitrophosphate and for mixtures of superphosphate plus equivalent nitrogen. Broadcast nitrophosphate was of little value, drilled dressings were much more effective. Superphosphate drilled with the seed produced consistently higher yields than broadcast superphosphate. Superphosphate plus equivalent nitrogen gave

higher average yields than nitrophosphate, both when broadcast and when drilled. When the dressings were broadcast, superphosphate was markedly superior to nitrophosphate, but when the fertilizers were drilled with the seed, average yields with superphosphate were only a little higher than with nitrophosphate.

Nitrophosphates may be substituted for mixtures containing water-soluble phosphorus for cereals, providing that they are drilled with the seed. Since nitrophosphates do not make cereals grow as rapidly as does superphosphate, even when drilled with the seed, such materials may give poor crops in conditions where the plants need a rapid start. The nitrophosphate tested contained rather more than one-quarter of its phosphorus in water-soluble form; the improved early growth observed where nitrophosphate was combine-drilled may have been largely due to this fraction of the fertilizer.

31. Cooke, G. W. (1956). The effect of some silicate slags on the utilization of soil and fertilizer phosphorus. *J. Sci. Fd Agric.* **7**, 56.

When certain silicates are applied to phosphorus-deficient soils they improve crop growth. The effects of waste slags, containing calcium silicate, from iron and steel manufacture on crop yields and on phosphorus uptakes were investigated.

In a pot experiment on barley grown on acid soil, ordinary blast-furnace slags gave smaller increases in yields than equal weights of calcium carbonate or "falling" haematite blast-furnace slags. Slags made by special steel-producing processes were more active than calcium carbonate and gave higher yields both with and without added phosphate.

In field experiments "falling" haematite blast-furnace slags behaved in the same way as ground limestone, and did not promote extra uptake of phosphorus by the crops. When no fertilizer phosphorus was applied, steel-furnace slags were more active than ground limestone, and gave higher yields of swedes containing more phosphorus. When superphosphate was applied, steel-furnace slags were still somewhat superior to limestone.

Both "falling" blast-furnace slags and the steel-furnace slags were active liming materials. Steel-furnace slags had the additional property of increasing the amounts of phosphorus taken up by the crops.

The reactions between silicates and soil phosphorus compounds require further study. Methods of characterizing products which promote the uptake of soil phosphorus by crops are needed.

32. Cooke, G. W., Jackson, M. V., Widdowson, F. V., Wilcox, J. C., & (Goodway, N. D.) (1956). Fertilizer placement for horticultural crops. *J. agric. Sci.* (In the press.)

In field experiments on vegetable crops dressings of appropriate fertilizers were placed 2 inches to the side of the seed and 2–3 inches below the soil surface and compared with the same amounts of fertilizer broadcast and worked into the surface soil. The work was carried out on ordinary arable land carrying rotations which included vegetables.

Placing fertilizer gave higher yields of cabbage, lettuce, beetroot, onions, broad beans, runner beans and maize, than broadcasting. Fertilizer, however applied, had no regular effect on the yield of french beans.

Both placed and broadcast fertilizer was tested at two rates of dressing. On average of all experiments on each crop, placing fertilizer at the low rate gave higher yields than broadcasting at the high rate. Broadcast fertilizer had little effect on yields of runner beans and broad beans, while placed dressings gave marked increases.

In two-thirds of all individual experiments placing gave higher yields than broadcasting, and in one-third of the experiments placing was significantly better than broadcasting. There were no instances of significantly higher yields from broadcasting as compared with placing.

Placing fertilizer made most of the crops grow more rapidly in the early stages than broadcasting; this improvement was often reflected in earlier maturity. For cabbage, lettuce and runner beans the relative gains from placing as compared with broadcasting fertilizer were higher at the first than at the second harvest.

By drilling fertilizer beside the seed of vegetable crops grown on ordinary soils, it is possible to economize in the dressings needed. In addition, some crops having placed fertilizers may be ready for market earlier. These

advantages may be very profitable where high-value crops are grown, and will justify the purchase of special placement drills.

A small series of field experiments on established Brussels sprouts and autumn-planted cabbages compared mid-season top-dressings of nitrogen fertilizer broadcast by hand over the whole soil surface with dressings placed at one point beneath the surface and near to the plants. The dressings used had practically no effect on yields of Brussels sprouts. Top-dressings broadcast in spring increased yields appreciably in two experiments on cabbage, and at both centres placing gave lower yields than broadcasting.

33. Cooke, G. W. & Gasser, J. K. R. (1955). Residual effects of phosphate fertilizers on a Wealden soil. *J. Soil Sci.* **6**, 248.

A field experiment was continued for 6 years, using a 2-year rotation of beetroot or swedes followed by potatoes. Normal dressings of superphosphate and also poultry manure were applied to the first-year crops. On other plots a small dressing of superphosphate (supplying 0·2 cwt. P_2O_5/acre) was applied to each crop.

For second-year crops of potatoes a fresh dressing of superphosphate supplying 0·2 cwt. P_2O_5/acre gave yields roughly equal to those given by 1·0 cwt. P_2O_5/acre applied as superphosphate the year before.

Poultry manure used to supply phosphate had slightly greater effects on both first- and second-year crops than superphosphate supplying the same amount of P_2O_5. Higher yields from poultry manure than from superphosphate may have been due in part to extra nitrogen supplied by the poultry manure, for which no allowance was made.

Only 10 per cent of the phosphate applied had been removed by the crops grown. Soil samples from individual plots were examined when the experiment was concluded. Total soil phosphate and dilute-acid-soluble soil phosphate had not been increased by experimental dressings of phosphate fertilizer. It is suggested that much of the fertilizer phosphate applied had moved down the soil profile below the cultivated layer.

34. Heintze, S. G. (1956). The effects of various soil treatments on the occurrence of marsh spot in peas and on manganese uptake and yield of oats and timothy. *Plant & Soil*, **6**, no. 5.

Marsh spot incidences of peas were increased in some cases concomitantly with decreases in total manganese content where sodium molybdate or zinc sulphate had been added to manganese-deficient soils. The amino-acid content was higher in affected than in healthy peas. On a manganese-deficient soil, steam treatment proved superior to application of various manganese materials in increasing the yield of oat grain. Treatments increasing the manganese content of the soil induced copper deficiency in younger leaves. Timothy grown on a manganese-deficient loam failed to respond in yield to addition of various manganese higher oxides to the soil, but manganese uptake was related to reducibility as well as to ultimate particle size of the oxides.

Pedology Department

35. (Bellis, E.), Stephen, I. & Muir, A. (1956). Gilgai phenomena in tropical black clays in Kenya. *J. Soil Sci.* **7**. (In the press.)

36. Bloomfield, C. (1955). A study of podzolization. VI. The immobilization of iron and aluminium. *J. Soil Sci.* **6**, 284.

The soluble ferrous and aluminium compounds that are formed by the action of aqueous leaf extracts on ferric and aluminium oxides are sorbed to varying degrees on soil colloids. The sorption effect is particularly marked on ferric oxide, and in this case the sorbed layer has the effect of inhibiting further solution of the unreacted oxide.

Direct comparison of the extent of sorption of the reaction products of different species indicates that the extent of sorption varies inversely as the efficiency of the species as a podzol former.

37. Bloomfield, C. (1955). The experimental production of podzolization. *Chem. & Ind.* 1596.

A preliminary account of the effect of leaf extracts on columns of ferruginous sand.

38. Bloomfield, C. (1955). Leaf leachates as a factor in pedogenesis. *J. Sci. Fd Agric.* **6**, 641.

A review of work on sesquioxide and clay movement delivered at a meeting of the Food and Agriculture Group of the Society of Chemical Industry.

39. Brown, G. (1955). The effect of isomorphous substitutions on the (001) reflections of mica- and chlorite-type structures. *Miner. Mag.* **30**, 657.

The effect of isomorphous substitutions on the structure factors of the 001 reflections has been calculated for mica-type and chlorite-type structures. In the micas (including illites) variations in diffracted X-ray intensities occur due to variations in the composition of the octahedral cation sheet and the interlayer cation sheet. The calculations for dioctahedral micas deal with compositions which lie within the field whose corner members are

$K_2(Al,Si)_8Al_4O_{20}(OH)_4$
$K_2(Al,Si)_8Fe_4O_{20}(OH)_4$
$(H_2O)_2(Al,Si)_8Al_4O_{20}(OH)_4$
$(H_2O)_2(Al,Si)_8Fe_4O_{20}(OH)_4$

and similar calculations have been made for trioctahedral micas. In the chlorite structure there are two kinds of sites for octahedrally co-ordinated cations, and both the kind of octahedral cations and their distribution between the two types of site affects the 001 intensities. The structure factors for 001 reflections of chlorite-type structures with compositions between

$(Mg,Al)_{12}(Si,Al)_8O_{20}(OH)_{16}$ and
$(Mg,Al)_4Fe_8(Si,Al)_8O_{20}(OH)_{16}$

have been calculated for both symmetrical and asymmetrical distributions of the octahedrally co-ordinated cations between the two types of octahedral sites. The effect of variations in intensities due to isomorphous substitution on the standard mineral method of quantitative mineralogical analysis is pointed out and an alternative method is suggested.

40. Gasser. J. K. R. & Bloomfield, C. (1955). The mobilization of phosphate in waterlogged soils. *J. Soil Sci.* **6**, 219.

Anaerobically fermenting plant material has virtually no effect on aluminium phosphate; calcium phosphates were readily attacked with consequent mobilization of both calcium and phosphate. Both phosphorus and iron were mobilized from ferric phosphates; atmospheric oxidation of the fermentation solutions caused precipitation of basic ferric phosphate together with organic matter, but significant amounts of both iron and phosphorus remained in solution after prolonged aeration. Phosphate was released from phosphated kaolinite and montmorillonite.

41. Greene-Kelly, R. (1955). The absorption of lithium by kaolin minerals. *J. phys. Chem.* **59**, 1151.

Keenan, Mooney and Wood (1951) * have shown that kaolinites saturated with different exchange cations adsorb different amounts of water at a given relative humidity, the amount taken up generally increasing with the hydration energy of the exchange cation. The important exception was lithium kaolinite, which showed the least water adsorption of any of the samples. Keenan *et al.* suggested that the lithium ions were not in the water film, but were accommodated among the surface layer of atoms of the mineral. The work described in this paper showed that lithium ions were fixed by kaolinite after drying at 200° C. and that after fixation the mineral still managed to adsorb more cations. The occurrence of fixation was thought to indicate that the cations had migrated into the crystal rather than being located in the surface layer of atoms and the persistence of cation adsorption after lithium fixation that some structural cation exchange was also occurring.

* Keenan, A. G., Mooney, R. W. & Wood, L. A. (1951). *J. phys. Chem.* **55**, 1462.

42. Greene-Kelly, R. (1955). An unusual montmorillonite complex. *Clay Min. Bull.* **2**, 226.

Sodium montmorillonite and pyridine form a regular complex of spacing 23·3 KX in the presence of traces of moisture. The minimum interlamellar composition necessary for the formation of the complex is approximately $NA(C_5H_5N)_4(H_2O)_2$. The intensities of the 001 reflections are considered incompatible with the complex having a five-layer structure, and an alternative arrangement is proposed.

43. Muir, A., Anderson, B., & Stephen, I. (1956). Characteristics of some Tanganyika soils. *J. Soil Sci.* (In the press.)

44. Muir, A. & Stephen, I. (1956). The superficial deposits of the lower Shire valley. *Colon. Geol. min. Res.* (In the press.)

45. Singh, S. (1956). Formation of dark-coloured clay-organic complexes in Black Soils. *J. Soil Sci.* **7**. (In the press.)

Study of the reaction of different clays with anaerobically fermented grass extracts has shown that montmorillonoids and other high base-exchange clays favour the formation of dark clay–organic complexes. Sodium clays sorb highest amounts of organic matter and give darkest products. Acidity (pH 3–5) favours the sorption and complex formation, an observation which suggests that the formation of the black colour in black cotton soils only takes place under at least periodic anaerobic conditions, as only then can these soils with an overall pH of 8 develop slight local acidity. It is probable that certain inorganic constituents of the organic extracts also contribute to dark colour formation.

Soil Microbiology Department

46. Kleczkowska, J. & Kleczkowski, A. (1956). Effects of clupein and its degradation products on a Rhizobium bacteriophage, on its host bacterium and on the interaction between the two. *J. gen. Microbiol.* **14**. (In the press.)

Clupein at 0·02–0·05 per cent in the liquid nutrient medium used to cultivate nodule bacteria, rapidly killed the bacteria and slowly inactivated the bacteriophage that attacked them. When added into the bacterial culture in liquid medium before adding phage, clupein prevented phage and bacteria from combining; when added after the two have combined, clupein interrupted further stages of phage–host interaction. Clupein at 0·0016 per cent acted bacteriostatically and slowed phage multiplication but did not stop it.

Trypsin and chymotrypsin hydrolyse clupein, trypsin breaking about twice as many peptide bonds as chymotrypsin. At a concentration corresponding to 0·02–0·05 per cent clupein, the peptide produced by chymotrypsin acted bacteriostatically in the liquid nutrient medium; the peptides inactivated phage much more slowly than did intact clupein, and they inhibited phage multiplication by interfering with the combination between phage and host. When added after phage and bacteria had combined, the peptides did not interfere with further stages of phage–host interaction. The smaller peptides produced by trypsin had no effect on host bacteria, phage or phage–host interaction.

Phage preparations partially inactivated by clupein had their activity partially restored by incubation with trypsin or chymotrypsin.

Clupein, but none of its hydrolic products, made phage with much non-phage material sedimentable by slow-speed centrifugation.

47. Meiklejohn, J. (1955). Soil microbiology. Some microscopical methods and results. *J. Queketi micr. Cl. ser.* 4, **4**, 171.

48. Meiklejohn, J. (1955). The local wind at Milfield, Northumberland. *Quart. J. R. met. Soc.* **81**, 468.

49. Meiklejohn, J. (1955). Nitrogen problems in tropical soils. *Soils & Fert.* **18**, 459.

50. Skinner, F. A. (1956). Inhibition of the growth of fungi by *Streptomyces* spp. in relation to nutrient conditions. *J. gen. Microbiol.* **14**. (In the press.)

Several species of soil actinomycetes arrested the growth of fungi by antibiotic secretions on agar media containing 10 g. glucose/l. On media of lower glucose concentration, the fungi continued to grow in the presence of the actinomycetes, but there was evidence that traces of antibiotic substances were still being formed by them. In sand cultures, moistened with liquid medium containing glucose, *Streptomyces albidoflavus* limited early growth of the fungus *Fusarium culmorum* by antibiotic action and also attacked preformed fungus mycelium directly. The effectiveness of these antagonistic mechanisms was lessened when the glucose concentration was decreased. The fungus and the actinomycete grew together on a variety of natural organic materials, but only when dried grass was used did the actinomycete arrest growth of the fungus at a distance.

51. Skinner, F. A. (1956). The effect of adding clays to mixed cultures of *Streptomyces albidoflavus* and *Fusarium culmorum*. *J. gen. Microbiol.* **14**. (In the press.)

An antibiotic present in culture filtrates of *S. albidoflavus* was inactivated by clays and by suspensions and extracts of soils. When the actinomycete was grown with *F. culmorum* in a mixture of sand and bentonite moistened with a nutrient solution containing glucose, it did not antagonize the fungus by antibiotic secretions. However, some suppression of fungus growth was observed even in the presence of bentonite, particularly when the glucose concentration was high; this effect was attributed to competition between the organisms for limiting nutrients. The actinomycete also lysed the contents of fungus mycelium in sand culture but did not do so when bentonite was added. The lytic agent appeared to differ from the antibiotic. Neither antibiotic action nor direct (lytic) attack on the fungus was demonstrated in sterilized soil.

52. Steenson, T. I. & Walker, N. (1956). Observations on the decomposition of chlorophenoxyacetic acids by soil bacteria. *Plant & Soil*, **7**. (In the press.)

Three strains of bacteria which can decompose 2 : 4-D, MCPA or *p*-chlorophenoxyacetic acid have been isolated from soil. One, that attacks 2 : 4-D but not MCPA, is a strain of *Flavobacterium peregrinum*, Stapp and Spicher, the second is an *Achromobacter* strain, which can decompose both 2 : 4-D and MCPA, and the third is an *Achromobacter* strain that decomposes *p*-chlorophenoxyacetic acid only.

The bacterial decomposition of 2 : 4-D in soil requires aerobic conditions.

The oxidation of 2 : 4-D or MCPA by bacteria involves adaptive enzyme formation. When grown on MCPA, the *Achromobacter* strain becomes adapted to oxidize both MCPA and 2 : 4-D, but grown on 2 : 4-D it oxidizes 2 : 4-D only. If either of the 2 : 4-D decomposing organisms are grown in a medium containing *p*-chlorophenoxyacetic acid, they produce a yellow, ether-soluble acidic substance, which is colourless in acid but yellow in neutral or alkaline solution. The oxidation of MCPA or 2 : 4-D by adapted bacterial cells is incomplete, only 11–12 atoms of oxygen per molecule of herbicide being consumed. When 2 : 4-D is decomposed in pure cultures of bacteria, about 75 per cent of the chlorine in the molecule is liberated in ionic form.

There is no evidence that either 2 : 4-dichlorophenol or 6-hydroxy-2 : 4-dichlorophenoxyacetic acid are intermediates in the breakdown of 2 : 4-D.

53. Stevenson, I. L. (1956). Antibiotic activity of actinomycetes in soil and their controlling effects on root-rot of wheat. *J. gen. Microbiol.* **14**. (In the press.)

A study has been made of conditions affecting the production of antibiotics in three soils by a number of unidentified *Streptomyces* spp. capable of inhibiting a variety of test organisms *in vitro*. In actinomycete-inoculated soils, antibiotic production was demonstrated only in sterile soils supplemented with a suitable organic source. The greatest accumulations of antibiotics were found in a neutral soil with added glucose (2·5 per cent), while under similar

conditions, no antibiotics, or only traces were recovered from acid and alkaline soils. Antibiotics, however, could be recovered from inoculated acid soil, following neutralization and the addition of glucose. Fresh grass (3 per cent), clover (3 per cent) and soy-bean meal (2 per cent) were also suitable supplements for antibiotic production by the majority of the actinomycetes, though the amounts of antibiotics were considerably less than in glucose-treated soils.

In greenhouse experiments the assessment of root-damage to wheat seedlings in sterile soil demonstrated that all the actinomycetes tested significantly reduced the degree of root-rot caused by *Helminthosporium sativum*. In the neutral and alkaline soils a relationship was evident between disease incidence and degree of antagonism exhibited by actinomycetes *in vitro*, suggesting that antibiotics were responsible. No such relationship was observed between disease control and the antibiotic-producing abilities of the actinomycetes in soil as determined by standard assay procedures.

54. Turner, E. R. (1955). The reaction between bentonite and certain naturally-occurring compounds. *J. Soil Sci.* **6**, 319.

The reaction leading to the formation of coloured complexes between bentonite and root secretions from clover plants and also between bentonite and certain chemical compounds has been investigated. The results indicate that iron present either in the lattice or as impurity in the bentonite is an important factor in the development of the coloured complexes.

The type of crystal lattice and of the pre-treatment of the bentonite on the complex formation with the root secretions from clover plants has also been studied.

Root secretions from several species of plants have been shown to form characteristic coloured complexes with added bentonite.

Attempts have been made to elute the complexes from the bentonite.

55. Walker, N. & Wiltshire, G. H. (1955). The decomposition of 1-chloro- and 1-bromo-naphthalene by soil bacteria. *J. gen. Microbiol.* **12**, 478.

Two species of naphthalene-utilizing bacteria from soil were able to metabolize 1-chloro- and 1-bromo-naphthalene. From cultures in which 1-chloro-naphthalene was the sole source of organic carbon, D-8-chloro-1 : 2-dihydro-1 : 2-dihydroxynaphthalene and 3-chlorosalicylic acid were isolated. 3-bromosalicylic acid was isolated from cultures with 1-bromonaphthalene and evidence of the formation of a " diol " compound obtained. The course of the metabolic pathways is discussed.

Botany Department

General Papers

56. Thorne, G. N. (1955). Nutrient uptake from leaf sprays by crops. *Field Crop Abstr.* **8**, 147.

57. Thurston, J. M. (1955). Controlling wild oats. *Fmr & Stk-Breed.* **69**, no. 3428, p. 75.

Research Papers

58. Humphries, E. C. (1956). The relation between the rate of nutrient uptake by excised barley roots and their content of sucrose and reducing sugars. *Ann. Bot.* (In the press.)

A re-examination of the results of previous experiments showed that the positive regression of the rate of nutrient uptake by excised barley roots on sugar content is attributable to the reducing sugar fraction. Partial regression coefficients of the rates of uptake of potassium, nitrogen and phosphorus on reducing sugar content were all positive; those on sucrose content were either not significant or negative.

These results were confirmed for potassium by experiments in which the sugar content of the roots was varied by varying the nitrogen supply to the

plants from which the roots were taken, by shading them or by supplying sucrose to the solutions in which the excised roots were held.

59. Humphries, E. C. & Kassanis, B. (1956). Effect of darkness on the constitution of tobacco leaves and susceptibility to virus infection. *Ann. appl. Biol.* **43**, 686.

Changes in insoluble-N, amino-N, amide-N, ammonia-N, nitrate-N, dry matter content and water content were determined in tobacco plants placed for varying periods in darkness before inoculation with tobacco aucuba mosaic virus. Nitrate-N content was highly correlated with susceptibility to infection, estimated by counts of necrotic local lesions, but the correlation was probably indirect and not causal. Changes in dry matter content, expressed either as dry matter per cent of fresh weight or separately on an absolute basis, also were correlated with susceptibility to infection.

60. Owen, P. C. (1956). The effect of infection with tobacco mosaic virus on the respiration of tobacco leaves of varying ages in the period between inoculation and systemic infection. *Ann. appl. Biol.* **44**. (In the press.)

Leaves of tobacco plants inoculated with tobacco mosaic virus were divided into three groups: (*a*) inoculated leaves; (*b*) younger non-inoculated leaves present at the time of inoculation; (*c*) leaves formed since inoculation, and the respiration rate on a dry weight basis of each group was compared with that of similar leaves from healthy plants. The respiration rate of inoculated leaves was increased by a constant amount for three weeks after inoculation, and then it was decreased. The respiration rate of group (*b*) leaves was not affected at any time, and that of group (*c*) leaves was decreased by 10 per cent when they showed symptoms. The increased respiration of the inoculated leaves occurred too soon to be related to virus formation, and may reflect an initial change in infected cells preparatory to virus synthesis. The subsequent decrease in respiration rate may be due to accumulation of virus material which is inactive in respiration.

61. Thorne, G. N. & Watson, D. J. (1955). The effect on yield and leaf area of wheat of applying nitrogen as a top-dressing in April or in sprays at ear emergence. *J. agric. Sci.* **46**, 449.

The yield and nitrogen content of grain of winter wheat were increased equally by 0·5 cwt. N/acre applied as an April top-dressing of " Nitro-Chalk " or by 8 sprayings of 2 per cent NH_4NO_3 solution applied to leaves or soil at the period of maximum leaf area, before and during ear emergence. April nitrogen gave a greater yield of straw than the late dressings.

The leaf area index of plots that received nitrogen in April was much larger than that of the other plots during May, but by 4 weeks after ear emergence it was less than that of plots receiving late nitrogen. Leaf area duration after ear emergence was the same for all nitrogen-treated plots, and the yield of grain divided by L.A.D. was nearly constant for all treatments.

62. Thorne, G. N. & Watson, D. J. (1956). Field experiments on uptake of nitrogen from leaf sprays by sugar beet. *J. agric. Sci.* **47**, 12.

When the leaves of sugar beet crops were sprayed on six occasions in late September and early October with 100 gal./acre of a 3 per cent solution of ammonium nitrate or equivalent urea, in two experiments about 70 per cent of the nitrogen was recovered in the plants in mid-October, compared with 40 per cent recovered from equivalent soil applications. In a third experiment the recovery from sprays was less than 40 per cent, but very little nitrogen was absorbed from soil dressings, so that the difference between the recoveries from spray and soil applications was nearly the same as in the other experiments. More than half the nitrogen absorbed from the sprays was in the leaf laminae, and about half of this was protein.

Spraying slightly increased the dry weight of tops, but not of roots. It caused losses in yield of sugar of 0, 2 and 5 cwt./acre respectively in the three experiments.

63. Warington, K. (1955). The influence of high concentrations of ammonium and sodium molybdates on flax, soybeans and peas grown in nutrient solutions containing deficient or excess iron. *Ann. appl. Biol.* **43**, 709.

Ammonium molybdate supplying 20 or 40 p.p.m. molybdenum prevented chlorosis caused by low iron supply in young flax plants, but sodium molybdate was effective only at the higher concentration. Temporary darkening of the green colour of the shoots was also produced by 40 p.p.m. molybdenum in iron-deficient soybean and pea plants, but was soon followed by more severe chlorosis. Symptoms of molybdenum toxicity always developed when 40 p.p.m. molybdenum were given and were reduced by an increase in iron supply. In flax the higher level of iron eventually proved toxic unless it was combined with 40 p.p.m. molybdenum. High molybdenum thus counteracted both iron deficiency and excess in flax.

High iron reduced the molybdenum content (p.p.m./d.m.) of both shoot and root in soybean, peas and, provided the iron was not excessive, in flax. High molybdenum usually reduced the iron content of the shoot, but greatly increased it in the root. Molybdenum-induced chlorosis could thus be partly attributed to inhibition in iron translocation, but the beneficial effect of high molybdenum or high iron on colour was not obviously correlated with the analytical data.

Biochemistry Department

Books

64. Pirie, N. W. (1955). *The numbers of man and animals.* Edited by J. B. Cragg & N. W. Pirie. Edinburgh : Oliver & Boyd.

65. Tracey, M. V. (1955). *Modern methods of plant analysis.* Edited by K. Paech & M. V. Tracey. Vols. 3 and 4. Berlin : Springer-Verlag.

General Papers

66. Kenten, R. H. (1955). Latent polyphenol oxidase in extracts of broad bean (*Vicia faba*, L.) leaves. *3rd int. Congr. Biochem., Brussels, Resumés des Communications*, p. 102.

67. Pirie, N. W. (1954). Fact and fancy in discussions about the origin of life. *Science & Culture, Calcutta* **20**, 261.

68. Pirie, N. W. (1954). Leaf proteins. *Vijnan-Karmee* (*J. Assoc. Sci. Workers of India*), *New Delhi*, **6**, 14.

69. Pirie, N. W. (1955). "Summing up" of Symposium on "The principles of microbial classification". *J. gen. Microbiol.* **12**, 382.

70. Pirie, N. W. (1955). New ways with trees. *Trees*, **19**, 74.

71. Pirie, N. W. (1956). Biochemical engineering. *Jubilee Souvenir of the Soc. of Biological Chemists*, India, p. 122.

72. Pirie, N. W. (1956). The anatomy of tobacco mosaic virus. *Advanc. Virus Res.* **4**.

73. Wiltshire, G. H. (1955). Changes in the organic acids of leaves associated with infection by plant viruses. *Commun. 3rd int. Congr. Biochem.* p. 102.

Research Papers

74. Kenten, R. H. & Mann, P. J. G. (1955). The oxidation of manganese by illuminated chloroplasts. *Biochem. J.* **61**, 279.

Chloroplast preparations oxidized Mn^{2+} in light but not, or to a much smaller extent, in darkness. In pyrophosphate the oxidation product accumulated as a soluble manganipyrophosphate. In phosphate an insoluble

oxidation product was formed which, like MnO_2, on treatment with pyrophosphate containing Mn^{2+} gave a soluble manganipyrophosphate. The oxidation products oxidize hydrazine and were estimated manometrically by this reaction or spectrophotometrically as manganipyrophosphate. A sensitive spectrophotometric method of estimating manganipyrophosphate has been described. The effect of variation of light intensity, period of illumination, concentration of chloroplast material and of Mn^{2+} was studied. Catalase partially inhibits the oxidation. Peroxidase increases the rate of oxidation. It is suggested that the oxidation is due, at least in part, to peroxidase systems and that a manganese oxidation–reduction cycle may play a part in the reactions of photosynthesis.

75. KENTEN, R. H. (1955). The oxidation of β-(3-indolyl) propionic acid and γ-(3-indolyl)-n-butyric acid by peroxidase and Mn^{2+}. *Biochem. J.* **61**, 353.

The oxidation of indolepropionic acid (IPA) and indolebutyric acid (IBA) by oxygen is catalysed by highly purified horseradish peroxidase preparations in the presence of Mn^{2+}. The mechanism of the reaction has not been elucidated, but the formation of hydrogen peroxide as an obligatory intermediate is suggested by the inhibiting effect of catalase. It is suggested that the previously reported oxidation of IPA and IBA by plant extracts may have been due to the presence of peroxidase and Mn^{2+} in the extracts.

76. MANN, P. J. G. & SMITHIES, W. R. (1955). Plant enzyme reactions leading to the formation of heterocyclic compounds. The formation of unsaturated pyrrolidine and piperidine compounds. *Biochem. J.* **61**, 89.

In reactions catalysed by plant amine oxidase, evidence was obtained of the formation of Δ'-pyrroline compounds from 1 : 4-diaminobutane, of 2 : 3 : 4 : 5-tetrahydropyridine compounds from 1 : 5-diaminopentane and 2 : 3 : 4 : 5-tetrahydropicolinic acid from D- and L-lysine. It is suggested that these ring compounds are formed by the spontaneous cyclization of the aldehydes or of the aldimines which are the probable products of the enzyme-catalysed reactions.

After hydrogenation of the products in presence of platinum black as catalyst, derivatives of pyrrolidine and piperidine were isolated with 1 : 4-diaminobutane and 1 : 5-diaminopentane respectively as substrates. A derivative of DL-pipecolinic acid was isolated from hydrogenated reaction mixtures with DL-lysine as substrate.

It is suggested that the amine oxidase-catalysed oxidation of 1 : 4-diaminobutane, 1 : 5-diaminopentane and L-lysine may represent the first stage in a biosynthesis of pyrrolidine and piperidine ring compounds.

77. MANN, P. J. G. & SMITHIES, W. R. (1955). Plant enzyme reactions leading to the formation of heterocyclic compounds. The formation of indole. *Biochem. J.* **61**, 107.

The oxidation of 2-(2-aminophenyl) ethylamine is catalysed by plant amine oxidase. The oxidation product accumulates in the reaction mixture as indole.

The oxidation of indole by hydrogen peroxide is catalysed by peroxidase.

78. PIERPOINT, W. S. (1956). The chromatography of leaf ribonuclease. *Biochim. biophys. Acta.*

The purification of leaf ribonuclease by cation exchange chromatography is described. The product is substantially free of other phosphatase activities, and is not inhibited by a number of anti-viral compounds and antibiotics.

79. PIERPOINT, W. S., (HUGHES, D. E., BADDILEY, J. & MATHIAS, A. P.) (1955). The effect of some pantothenate derivatives on growth and Co-enzyme A synthesis in bacteria. *Biochem. J.* **61**, 190–197.

80. PIERPOINT, W. S., (HUGHES, D. E., BADDILEY, J. & MATHIAS, A. P.) (1955). The phosphorylation of pantothenic acid by Lactobacillus arabinosus 17–5. *Biochem. J.* **61**, 368–374.

81. Pirie, N. W. (1956). Some components of tobacco mosaic virus preparations made in different ways. *Biochem. J.* (In the press.)

Part of the phosphorus in many TMV preparations becomes soluble in trichloroacetic acid when the preparations are incubated. There is evidence that this is caused by the fission of normal leaf nucleoprotein by ribonuclease.

Some steps in the purification remove the normal nucleoprotein, but other properties of the virus, notably its precipitability by ammonium acetate, are altered at the same time.

Ribonuclease is more difficult to remove, and it is detectable in all preparations. The smallest amount is found in those that have been ultracentrifuged from salt solutions in the presence of nucleic acid. TMV that has been denatured by TCA is a particularly sensitive system for detecting this residual nuclease.

82. Pirie, N. W. (1956). A disintegrator for use with small quantities of fresh leaves. *J. agric. Engng Res.* **1**, 81.

A unit for pressing batches of leaves up to 50 g. in weight through a slot of adjustable width is described. By this means the leaves are ground to a controlled fineness. For work on a small scale this method of grinding is preferable to others because it is repeatable, there is no need to add any fluid to the leaves and the ground material can be recovered quantitatively.

Pirie, N. W. & Bawden, F. C. (1956). Observations on the anomalous proteins occurring in extracts from plants infected with strains of tobacco mosaic virus. *J. gen. Microbiol.* **14**. (In the press.)

For summary see no. 102.

83. Tracey, M. V. (1955). Cellulase and chitinase in soil amoebae. *Nature, Lond.* **175**, 815.

The methods used in demonstrating the production of cellulase and chitinase by three species of soil amoebae are described and an attempt is made to relate the amount formed with that found in the snail.

84. Tracey, M. V. (1955). A rapid colorimetric distinction between glucosamine and galactosamine. *Biochim. biophys. Acta*, **17**, 159.

The differential colour depression produced by the presence of borate in the Elson & Morgan reaction is the basis of the method described.

85. Tracey, M. V. (1955). Chitinase in some basidiomycetes. *Biochem. J.* **61**, 579.

It is shown that fungi of the *Lycoperdon* group are a useful source of active chitinase. Chitinase was found to respond to the addition of protein in a manner similar to that found by Whitaker with cellulase. Methods for the viscometric and hydrolytic assay of chitinase are described.

86. (Clarke, P. H. &) Tracey, M. V. (1956). The occurrence of chitinase in some bacteria. *J. gen. Microbiol.* **14**, 1.

A survey of chitinase production by representative species of the main groups of bacteria. Chitinase is produced by some but not all of the soil and water bacteria; it appears to be a constitutive enzyme in many species, and its occurrence may prove of diagnostic value.

Walker, N. & Wiltshire, G. H. (1955). The decomposition of 1-chloro- and 1-bromonaphthalene by soil bacteria. *J. gen. Microbiol.* **12**, 478.

For summary see no. 55.

87. Wiltshire, G. H. (1956). The effect of darkening on the susceptibility of plants to infection with viruses. 1. Relation to changes in some organic acids in the French bean. *Ann. appl. Biol.* (In the press.)

The organic acid composition of extracts from leaves from plants under different environmental conditions was compared with the susceptibility of the same leaves to tobacco necrosis virus.

88. Wiltshire, G. H. (1956). The effect of darkening on the susceptibility of plants to infection with viruses. 2. Relation to changes in ascorbic acid content of French bean and tobacco. *Ann. appl. Biol.* (In the press.)

The susceptibility of French bean leaves to tobacco necrosis virus and of tobacco leaves to tomato aucuba mosaic virus was compared with the ascorbic acid contents of the same leaves after darkening the plant for different periods.

Plant Pathology Department

General Papers

89. Bawden, F. C. (1955). Virus diseases of plants (The Fernhurst Lecture). *J. R. Soc. Arts*, **103**, 436.

90. Bawden, F. C. (1955). The classification of viruses. *J. gen. Microbiol.* **12**, 362.

91. Broadbent, L. & Burt, P. (1955). The control of potato virus diseases by insecticides. *Agric. Rev. Lond.* **1**, 60.

92. Buxton, E. W. (1955). Fusarium Yellows of Gladioli. *Gladiolus Annual*, 1955, 27.

93. Hull, R. (1955). Mangold clamps and sugar beet growers. *Brit. Sug. Beet Rev.* **23**, 123.

94. Hull, R. (1955). Sugar Beet Yellows in Great Britain, 1954. *Plant Path.* **4**, 134.

95. Hull, R. (1955). Virus problems in sugar beet. *Proc. nat. Crop Prot. Conf.* 1955.

96. Hull, R. (1955). Sugar Beet Yellows. Ministry of Agriculture, Releases to the provincial press :

(*a*) February : The importance of clearing up infection sources in spring.

(*b*) October : Measures taken now will help to ensure a healthy crop next year.

97. Hull, R. (1955). Beet Yellows Virus. The importance of garden crops as infection sources. *J. R. hort. Soc.* **80**, 88.

98. Kassanis, B. (1955). Carnation latent virus. *Proc. 2nd Conf. Potato Virus Dis. Lisse-Wageningen.*

99. Kleczkowski, A. (1954). Intermediate stages of some viruses and enzymes in the course of their inactivation by ultraviolet radiation. *Proc. 1st Int. Photobiol. Congr.*, 59.

Research Papers

100. Bawden, F. C. & Harrison, B. D. (1955). Studies on the multiplication of a tobacco necrosis virus in inoculated leaves of French bean plants. *J. gen. Microbiol.* **13**, 494.

By treating leaves of French bean (*Phaseolus vulgaris* L.) in various ways at intervals after they were inoculated with the Rothamsted tobacco necrosis virus, a series of events in infected cells was detected and approximately

timed. Treating leaves with ribonuclease, or floating them in water, in the first hour after inoculation decreases the number of infections; these treatments fail to do so later, perhaps because the virus has become firmly attached to some host component, or because cells injured at inoculation have healed and no longer allow virus particles to diffuse out or ribonuclease in.

After 2 hours at 25° the virus is less readily inactivated by ultra-violet radiation than previously, suggesting that infected cells now contain more of substances that absorb radiation of 2537 Å. After 4 hours the inactivation curve with ultra-violet radiation deviates from the course of a first-order reaction, probably because some infected cells now contain more than one potentially infective particle. After 6 hours the formation of some lesions cannot be prevented by irradiation, suggesting that newly formed virus has spread from initially infected cells to deeper tissues, where it is protected from inactivation. At 16° the mean time for virus to spread from the initially infected cells is 12·5 hours, and it probably spreads from some cells by 8 hours and from most by 15 hours.

Newly formed virus is not detectable in extracts of inoculated leaves until after it has spread from the epidermis to deeper tissues. Up to 20 hours after inoculation most of the extractable virus seems to come from the epidermis, but later it comes predominantly from other tissues.

101. Bawden, F. C. & Kleczkowski, A. (1955). Studies on the ability of light to counteract the inactivating action of ultra-violet radiation on plant viruses. *J. gen. Microbiol.* **13**, 370.

Of seven plant viruses tested, all except tobacco mosaic showed the phenomenon of photo-reactivation, i.e., plants exposed to visible light after inoculation with preparations partially inactivated by ultra-violet radiation produced more local lesions than plants kept in darkness. Five strains of tobacco mosaic virus, which differed widely in their pathogenicity and other properties, were tested, but none showed the phenomenon. Of the six viruses that did, potato X showed it much the most strongly, tomato bushy stunt and a tobacco necrosis virus the least; cabbage black ringspot, cucumber mosaic and tobacco ringspot were intermediate.

Photo-reactivation does not occur immediately after plants are inoculated. With irradiated preparations of potato virus X, most particles need about 30 minutes to reach the state in which their ability to infect is affected by light; once in this state, exposure to daylight for 15 minutes gives almost complete photo-reactivation. Some irradiated particles respond to light of 80 f.c., but others need brighter light; no additional response occurs when light intensity is increased above 600 f.c. The sensitive state of potato virus X persists for about 1 hour in plants kept in darkness, after which the particles seem to be permanently inactivated.

With antibodies and enzymes, a constant amount of absorbed energy decreases the activity of a unit weight by a given fraction. This rule does not apply to plant viruses, which lose infectivity with less absorbed energy than the rule predicts. If viruses are more sensitive because they contain nucleic acid, their sensitivity is not a direct function of their content of nucleic acid. Potato virus X has the same nucleic acid content as strains of tobacco mosaic virus, but is inactivated by less absorbed energy, and individual strains of tobacco mosaic virus also differ by factors of two in the amount of radiation needed to decrease their infectivity by a given fraction.

102. Bawden, F. C. & Pirie, N. W. (1956). Observations on the anomalous proteins occurring in extracts from plants infected with strains of tobacco mosaic virus. *J. gen. Microbiol.* **14**. (In the press.)

When extracts from plants infected with various strains of tobacco mosaic virus were ultracentrifuged, the non-infective supernatant fluids still contained 0·5–5 per cent of the protein serologically related to the viruses. The small, mostly spherical, particles aggregated to form short rods as the antigen was progressively purified by precipitation with acid or salts. It formed long rods when heated in pH 5·5 buffer or when incubated with trypsin. As the particles increased in length, their serological behaviour in precipitation tests changed from " somatic " to " flagellar " type.

Purified preparations of the unsedimented antigen from plants infected

with either of two virus strains contained 0·1–0·2 per cent phosphorus, seemingly in the form of a ribose nucleic acid. No evidence was obtained that the preparations were mixtures containing some particles with the 0·5 per cent phosphorus characteristic of infective virus and some particles of protein free from nucleic acid.

One virus strain produced a higher ratio than the others of unsedimented to sedimented antigen. The amount of unsedimented antigen was correlated with the total content of anomalous protein when the protein was increasing rapidly, but later it fluctuated unpredictably. No conditions were found that consistently favoured its accumulation, but when plants systemically infected with the type strain were kept at 36°, the total amount of antigen decreased, while the amount unsedimented sometimes increased.

The proportion of the total antigen now obtained as poorly infective nucleoprotein is much less than 10 years ago, when a third of it sedimented in the ultracentrifuge but failed to compact into a pellet. Now the uncompacted sediment, with all the host plants and virus strains used, contains only a trivial part of the total antigen.

The virus released into sap when leaves are minced is, weight for weight, more infective than the virus that remains in the leaf residues until it is released by fine grinding.

103. Broadbent, L. (1955). The effects of dates of planting and harvesting potato crops on virus-disease incidence and yield. *Ann. appl. Biol.* **43**, 149.

An experiment was done during 1953 to find out the effect of different planting and harvesting dates on the incidence of virus disease in the following year. The experiment will be repeated for 3 years. The results of the experiment might be expected to show if the widely held belief that early-lifted " immature " seed is superior to mature seed is (*a*) true, and (*b*) due to virus infection or physiological differences, or both.

Tubers were planted at monthly intervals from April to August. One tuber infected with leaf-roll virus was planted per plot, and the trial was near sources of leaf roll and Y viruses.

Half the plots of each planting were lifted 12 weeks after planting, the remainder after the haulm died.

The yield of tubers in 1953 varied between 9 tons/acre (May planting) and 4 (April, July and August plantings) when harvested after 12 weeks, but when left to maturity it fell from 26 tons/acre (April planting) to 4 (August planting).

During 1954 the progeny of tubers lifted after the haulm died in 1953 significantly outyielded those lifted after 12 weeks' growth (both healthy and leaf-roll virus-infected tubers). Leaf-roll virus caused a loss in yield of about 70 per cent.

The incidence of virus disease was small in the April, May and August plantings lifted after 12 weeks, and in the August planting lifted after the haulm died. The healthiest crop in 1954 was obtained from the April planting lifted after 12 weeks because aphids were few during the early months of 1953.

104. Broadbent, L. & Heathcote, G. D. (1955). Sources of overwintering *Myzus persicae* (Sulzer) in England. *Plant Path.* **4**, 135.

Winged *Myzus persicae* (Sulzer) that develop on *Prunus* spp. from colonies developing from eggs can be distinguished morphologically from those that develop on herbaceous hosts from colonies that overwintered viviparously. Of 238 *M. persicae* trapped during recent springs in potato, brassica and narcissus crops in different parts of England, two only had come from *Prunus* spp. Most *M. persicae* overwinter as eggs on the Continent of Europe, but in England most overwinter as living aphids.

105. Buxton, E. W. (1955). Fusarium diseases of peas. *Trans. Brit. mycol. Soc.* **38**. (In the press.)

Cultures of *Fusarium oxysporum* and *F. oxysporum* var. *redolens*, isolated from diseased pea plants growing in East England, differed in their pathogenicity. Most cultures of *F. oxysporum* behaved like the American physiologic race 1 of *F. oxysporum* f. *pisi*, but some were only weak pathogens, and one infected pea varieties resistant to races 1 and 2. This is provisionally

named race 3A. A culture of *F. oxysporum* var. *redolens* caused a wilt indistinguishable from that caused by race 1 of *F. oxysporum* f. *pisi*. Pea wilt was the main cause of crop failures due to Fusaria up to mid-June.

Pathogenic and non-pathogenic forms of *F. solani* were also isolated from diseased peas, but usually only after mid-June. From plants showing characteristic footrot, only *F. solani* was isolated, but towards the end of June many diseased plants had symptoms characteristic of both wilt and footrot. These symptoms are thought to resemble those previously called " St. John's Disease ", and from such plants both *F. oxysporum* and *F. solani* were always isolated.

When *F. oxysporum* f. *pisi* race 1 was inoculated to peas together with either pathogenic or non-pathogenic cultures of *F. solani*, the pea plants were less severely affected than when inoculated with race 1 alone.

106. Buxton, E. W. & Richards, Marilyn G. (1955). Pathogenic strains of *Fusarium oxysporum* Fr. distinguished by their differential tolerance to inhibition by various actinomycetes. *J. gen. Microbiol.* **13**, 99.

Cultures of sixteen different soil actinomycetes were tested for their ability to inhibit the growth of eight pathogenic strains of *Fusarium oxysporum* Fr. on agar media. Three of the actinomycetes did not inhibit growth, and nine inhibited growth of all strains equally, but the other four actinomycetes consistently inhibited the growth of individual strains to different extents. The differences provide an *in vitro* test which distinguishes between certain pathogenic strains of *Fusarium* that are otherwise indistinguishable in culture.

107. Cornford, C. E. (1955). Maleic hydrazide as a shoot depressant for clamped mangolds and fodder beets. *Plant Path.* **4**, 89.

A solution of 0·25 per cent of maleic hydrazide sprayed on growing mangold plants in mid-October, and on fodder beet in early November, strongly inhibited the growth of sprouts on the roots stored in clamps or in a warm cellar, and probably reduced sprouting to well below the amount necessary to support an aphid population over the winter. The time of spraying had an important effect on the extent to which sprouting was suppressed.

108. Harrison, B. D. (1955). Studies on the effect of temperature on virus multiplication in inoculated leaves. *Ann. appl. Biol.* **44**. (In the press.)

The rate at which the Rothamsted tobacco necrosis virus accumulates in inoculated French bean leaves increases with rising temperature to 22° C. and then decreases. Three days after inoculation, leaves at 22° C. contain 4,000 times as much virus as at 10° C. and 1,000 times as much as at 30° C. At all temperatures the rate of accumulation may depend on the balance between synthesis and inactivation, but inactivation becomes increasingly important with rise of temperature above 22° C., and as the virus content of the leaves increases. Above 22° C., the rate of multiplication may increase but less rapidly than the rate of inactivation, and exposing inoculated leaves to ultra-violet radiation at various intervals after inoculation suggests that at 30° C. RTNV multiplies in and moves from the initially infected epidermal cells in slightly less than the 6 hours needed at 22° C. Thirty hours are needed at 10° C. Newly-formed virus is rapidly inactivated at 30° C. Raising the ambient temperature also decreases the numbers of local lesions, possibly by increasing the chances that the introduced virus particles will become inactivated. Increasing the virus content of the inoculum above the level giving one lesion per sq. cm. does not increase the subsequent virus content of inoculated leaves.

At temperatures of 30° C. and below, tomato aucuba mosaic virus produces necrotic lesions in leaves of tobacco and *Nicotiana glutinosa*, whereas above 30° C. the lesions are chlorotic. In both hosts this virus multiplies more rapidly when the infected cells are killed.

109. Hirst, J. M., Storey, I. F., Ward, W. C. & Wilcox, H. J. (1955). The origin of apple scab epidemics in the Wisbech area in 1953 and 1954. *Plant Path.* **4**, 91.

In England three causes of early spring infections of apple scab (*Venturia inaequalis* (Cooke) Wint.) have been proposed; conidia from infected twigs or

infected bud scales, or ascospores from fallen leaves. Power-operated suction spore traps allowed the frequency of both types of spore in orchard air to be estimated more accurately than did the types of spore trap previously used in England. In a Bramley's Seedling orchard at Wisbech, in both 1953 and 1954, conidia were rare but ascospores very common, reaching over 2,000 per cu. m. of air during a 2-hour period on 1 May 1954 soon after the end of a dry spell. Rain regularly caused ascospore liberation, from before bud-burst at the end of March until petal-fall in late May. All the evidence suggests that ascospores caused the early infections; these first occurred in 1953 at bud-burst, but in 1954 not until green-cluster.

110. Humphries, E. C. & Kassanis, B. (1955). Effects of darkness on the constitution of tobacco leaves and susceptibility to virus infection. *Ann. appl. Biol.* **43**, 686.

For summary see no. 59.

111. Kleczkowski, A. (1955). The statistical analysis of plant virus assays: a transformation to include lesion numbers with small means. *J. gen. Microbiol.* **13**, 91.

The numbers of local lesions (x) produced by different leaves when inoculated with the same virus preparation deviate greatly from a normal distribution, and the standard errors of x's depend on their magnitude. Before customary statistical analyses are applicable to results of infectivity assays, x's must be suitably transformed. When mean values of x are greater than about 10, the transformation $z = \log_{10}(x + c)$ (where c is a constant) is satisfactory, but inapplicable with smaller numbers. In some work the use of poorly infective inocula is unavoidable, and to allow statistical analysis of results in such work a new transformation $z = \log_{10}\frac{1}{2}[x + c + \sqrt{(x^2 + 2cx)}]$ is derived. This operates satisfactorily when mean numbers of x are greater than about 1·5. The results of the two transformations converge as x increases. Values of z are tabulated to make the use of the new transformations as quick as that of the other transformation.

Kleczkowska, J. & Kleczkowski, A. (1955). Effects of clupein and of its degradation products on a *Rhizobium* bacteriophage, on its host bacterium and on the interaction between the two. *J. gen. Microbiol.* **14**. (In the press.)

For summary see no. 46.

112. Last, F. T. (1955). The spore content of air within and above mildew-infected cereal crops. *Trans. Brit. mycol. Soc.* **38**, 453.

In addition to *Erysiphe*, the most abundant spores in the air in mildew-infected cereal crops were *Cladosporium, Alternaria, Sporobolomyces* and *Tilletiopsis*. On dry days *Sporobolomyces* and *Tilletiopsis* were most numerous at 04·00 G.M.T. and *Erysiphe, Cladosporium* and *Alternaria* at 16.00 G.M.T. *Sporobolomyces* predominated throughout wet days when *Alternaria* did not occur.

Between 12.00 and 16.00 G.M.T. on dry days, *Cladosporium* spores were the most abundant; their concentration increased progressively from April to July. *Erysiphe* conidia were few during April and May, and increased rapidly to a maximum in June; *Alternaria* was very rare until July. In smutted crops, *Ustilago* spores were also very rare in April and May but equally plentiful in June and July.

The spore concentration was always greater within than above the crop, when the spores were formed on the crop. More *Erysiphe* and *Cladosporium* spores occurred near the ground than at the top of the crop; there was little difference between the concentrations of *Ustilago*.

The date of sowing affected the spore concentrations; *Cladosporium* and *Sporobolomyces* were more numerous in an early- than in a late-sown wheat crop; the differences were least near harvest. *Erysiphe* conidia were more numerous in the late-sown crop.

Higher concentrations of *Cladosporium, Alternaria, Erysiphe, Sporobolomyces* and *Tilletiopsis* were found in a wheat crop given fertilizer (N, P and K) than in a crop given no fertilizer.

113. Last, F. T. & Buxton, E. W. (1955). Photo-reactivation of *Botrytis fabae* Sardiña measured by a local-lesion technique. *Nature, Lond.* **176**, 655.

Irradiating conidia of *Botrytis fabae* Sardiña and of *Uromyces fabae* (Pers.) de Bary with ultra-violet light reduced their infectivity, as measured by the numbers of lesions produced on half-leaflets of broad bean plants (*Vicia faba* L.). A satisfactory method of inoculation for local lesions was to rub the leaves with spore suspensions on the fore-finger. The damage to spores by the radiation was counteracted by exposing them to daylight immediately after the irradiation. The proportion of irradiated spores that infected was increased by extending the time the spores were exposed to daylight before inoculation to leaves or by exposing leaves to daylight after they were inoculated.

114. Macfarlane, I. (1955). Variation in *Plasmodiophora brassicae* Woron. *Ann. appl. Biol.* **43**, 297.

Three races of *Plasmodiophora brassicae* were distinguished by their different capacities to form clubs on different hosts; one failed to club turnip and swede, and the others were identified by their effects on different turnip and swede varieties.

In contrast to their effects on clubbing, these races caused equal numbers of root-hair infections with zoosporangia, on all crucifers tested. It is evidently the later stages in the life cycle of the pathogen that cannot develop in club-root-resistant hosts.

Some partially resistant varieties became clubbed when spore concentrations were increased above the level necessary to cause complete infection of susceptible varieties.

Varieties susceptible to a particular race of *P. brassicae* do not seem to fall into any taxonomic group within the Cruciferae. Susceptible and resistant varieties may belong to the same species or may occur throughout a number of species and genera.

115. Salt, G. A. (1955). Effects of nitrogen applied at different dates, and of other cultural treatments on eyespot, lodging and yield of winter wheat. Field experiment 1952. *J. agric. Sci.* **46**, 407.

Lodging and yield of winter wheat were studied in a factorial experiment on land infested with the fungus *Cercosporella herpotrichoides* Fron. causing eyespot. Two varieties, Squareheads Master 13/4 with long, and Bersée with short straw, were compared at two seed rates; sulphate of ammonia was applied at 0, 2 and 4 cwt./acre at four different dates; four of the eight blocks of ten plots were sprayed in March with sulphuric acid to control eyespot.

Lowering the seed rate from 3 to 1½ bushels/acre decreased eyespot and the area lodged, and increased the mean yield of the two varieties by 4·9 cwt./acre in unsprayed and 2·1 cwt./acre in sprayed plots. Spraying the variety Squareheads Master decreased the straws with severe lesions from 66 to 17 per cent, the area lodged from 95 to 36 per cent, and increased grain from 22·4 to 32·4 cwt./acre; spraying Bersée decreased severe lesions from 56 to 15 per cent, lodging from 54 to 1 per cent and increased yield from 32·6 to 43·5 cwt./acre.

The mean percentage infection at harvest was little affected by nitrogen applied in March, April or May, but was decreased by nitrogen applied in October. In contrast, the time of applying nitrogen greatly affected the weight of straw and the extent of lodging, both of which were increased more by top dressings in March and April than by those in May. Plots that received nitrogen in March and October had similar weights of straw, but the latter, with less eyespot, lodged less. Where lodging was slight, grain yields were increased equally by nitrogen applied at each date; where lodging was extensive, yields were depressed by dressings in March and April, and increased by those in October and May. Sulphate of ammonia applied at 0, 2 and 4 cwt./acre to sprayed (upright) plots of Bersée yielded respectively 36·8, 42·9 and 47·3 cwt. of grain, whereas applied to unsprayed (completely lodged) plots of Squareheads Master yielded only 22·4, 22·0 and 22·9 cwt./acre respectively.

116. Watson, M. A. (1955). The effect of sucrose spraying on symptoms caused by beet yellows virus in sugar beet. *Ann. appl. Biol.* **43**, 686.

When leaves of sugar-beet plants infected with beet yellows virus were sprayed daily with 10 per cent sucrose solution, yellowing symptoms were intensified. When the light intensity was reduced to less than half of full daylight, yellowing symptoms were suppressed more completely on unsprayed than on sprayed plants.

Spraying with 2·5 per cent sucrose solution increased the carbohydrate content of the leaves, and the effect on symptom intensity and carbohydrate content were closely correlated in both shaded and unshaded plants. As the severity of symptoms was increased by supplying carbohydrate without change in the light conditions, it is concluded that light intensity affects symptom expression by varying the carbohydrate content of the leaves through its influence on photosynthesis.

Sucrose spraying increased the yield of roots of healthy and infected plants by about the same amount. Most of the increase was sucrose, showing that sprayed sucrose was translocated to the roots from the leaves of both healthy and infected plants.

Measurements of diurnal changes in carbohydrate concentration support the view that movement of carbohydrate out of infected leaves is not stopped by infection.

Nematology Department

General Papers

117. (Basden, E. B.) & Goodey, J. B. (1955). A nematode parasite of *Drosophila*. *Nature, Lond.* **175**, 431.

118. (Moreton, D. B., John, M. E.) & Goodey, J. B. *Aphelenchoides* sp. destroying mushroom mycelium. *Nature, Lond.* (In the press.)

119. Peters, B. G. (1955). Control of plant nematodes. *Rep. Progr. appl. Chem.* **39** (1954), 721.

120. Peters, B. G. (1955). Soil-inhabiting nematodes (p. 44); A note on simple methods of recovering nematodes from soil (p. 373); A note on handling and processing nematodes (p. 417); in: *Soil Zoology*. Edited by D. K. McE. Kevan. London: Butterworth.

Research Papers

121. Doncaster, C. C. (1956). Electronic flash in photomicrography. *Nematologica*, **1**, 51.

An apparatus for taking photomicrographs of living nematodes and other microscopic organisms by means of high-speed flash is described in detail. Photographs taken with this equipment are used for comparison with " dead " mounts, and accurate measurements of whole or parts of living microscopic organisms can be obtained.

122. Franklin, M. T. (1955). A redescription of *Aphelenchoides parietinus* (Bastian, 1865) Steiner, 1932. *J. Helminth.* **29** (1/2), 65.

After pointing out that *Aphelenchoides parietinus* as now known is probably an aggregate of several species, the author gives a detailed description of the females of a population collected from the same locality and habitat as that from which Bastian made the collection on which he based his description. The population contained no males.

123. (Brown, E. B.) & Goodey, J. B. (1956). Observations on a race of stem eelworm attacking lucerne. *Plant Path.* **5**, 28.

A field trial showed that the lucerne race of the stem eelworm attacked lucerne var. " Grimm " and alsike clover. " Du Puits " was slightly attacked though little damaged. Oats, other legumes and the American varieties of lucerne, " Synthetic A " and " Nemastan " were resistant. The American varieties are not suitable for British conditions.

124. Goodey, J. B. & (Brown, E. B.) (1956). Stem eelworm attacking carrots. *J. Helminth.* **29**, 187.

The host range of a population of stem eelworm, found attacking carrots near Chatteris, was investigated, in the field and in pots. *Vicia faba*, oats and celery were attacked in the field, the same plants, garden peas and potatoes in pots. The population was not one of the typical oat race.

125. Goodey, J. B. & Franklin, M. T. (1956). The nematode parasites of plants catalogued under their hosts. [2nd edition of T. Goodey, 1940.] Farnham Royal: Commonwealth Agricultural Bureau. (In the press.)

In this second edition the contents have been completely revised, rearranged and brought up to date. Names of nematodes now follow the latest and generally accepted systematics. New records have been added so that the catalogue is complete, as far as possible, up to the end of 1954. There are about 6,000 entries and a bibliography with nearly 800 references.

126. Hesling, J. J. (1956). Some observations on *Heterodera major*. *Nematologica*, **1**, 56.

The hatching of cysts of *Heterodera major* is impaired by drying; dried cysts immersed in water do not appear to recover hatchability. The recovery of *H. major* cysts for population estimation purposes may present difficulty because new and full cysts may not float. A technique for the recovery of viable cysts of *H. major* is described. Cysts obtained by this method should be stored moist at about 2° C. to prevent hatching, which appears to be stimulated by increase in temperature.

127. (Lownsbery, B. F.) & Peters, B. G. (1955). The relation of the tobacco cyst nematode to tobacco growth. *Phytopathology*, **45**, 163.

An outdoor pot experiment showed that height and final weight of tobacco plants were inversely proportional to the logarithm of the initial density of viable encysted larvae of *Heterodera tabaccum* in the soil. This was true over the range 50–3,200 larvae/g. of soil. A tenfold increase in density led to a loss in plant weight of 139 g. for normal fertilized plants and 25 g. for smaller unfertilized plants. The highest density which maintained itself was 1,000 larvae/g. soil, resulting in a reduction of 25 per cent in weight of normally fertilized plants. It is not yet known whether field populations follow these pot fluctuations; the 1953 field increase was of the same order as the increase in the pot experiment.

In the field, tobacco plants grown in dichloropropene–dichloropropane-treated soil were 15–22 per cent taller than plants grown in untreated soil, but nematode reduction was confounded with other fumigant effects.

128. Peters, B. G. (1955). The combined use of nematicidal soil fumigants and solubilized chemicals. *J. Helminth.* **29**, 81.

Fumigation with " DD mixture " results in a considerable loss of vapour from the surface layer of the soil, and this loss is only moderately reduced by using a water seal or non-gas-tight seal of foil. A residue of potato-root eelworm survivors are left in this top 2 inches of soil. These can be dealt with by treating the soil surface with a similar solution of *p*–*m*-cresol solubilized by the method of Staniland and Stone. The two treatments act independently at all levels. The practical implications may be of importance in treating glasshouse soils.

129. Reid, E. (1955). A rolling method for opening cysts of potato-root eelworm. *Plant Pathology*, **4**, 28.

Soaked cysts are placed along a channel in a metal slide and opened by rolling a glass rod over them. The clearance prevents any loss of eggs or larvae. The opened cysts are then agitated with an electric mixer to free the contents. Aliquot samples are then taken for counting.

Insecticides Department

General

Broadbent, L. & Burt, P. (1955). The control of potato virus diseases by insecticides. *Agric. Rev.* **1**, 60.

130. Potter, C. Work in England on the effect of insecticides and other chemicals used in plant protection on beneficial insects and insect populations. *Int. Union for the Prot. of Nature.*

131. Way, M. J. (1955). Beans and Blackfly. *Agric. Rev. Lond.* **1**, 1.

Research Papers

132. Burt, P. E. & Ward, J. (1955). The persistence and fate of DDT on foliage. I. The influence of plant wax on the toxicity and persistence of deposits of DDT crystals. *Bull. ent. Res.* **46**, 39.

The persistence and toxicity of DDT crystals on thin layers of plant wax were studied. Deposits of crystalline DDT at rates of 2–8 μg./sq. cm. were applied to glass plates, plain or coated with a 0·5-μ layer of wax obtained from leaves of sisal or cabbage. The plates were stored for various periods at 18° and 43° C. (representing temperate and tropical leaf-temperatures). DDT remaining after storage was estimated biologically by means of its contact action on adult *Tribolium castaneum* (Hbst.), and chemically by a modification of the Schechter–Haller method. At 18° C. there was no significant change in any of the deposits when estimated chemically. But biological estimation showed that, although the toxicity of the deposits on waxed plates was unchanged, that on glass plates was doubled after storage for 8 days. The reason for this change was not discovered. At 43° C. the amount of DDT, estimated both chemically and biologically, diminished rapidly and was negligible after 26 days. The loss of toxicity at 43° C. was shown to be accompanied by loss of weight of the deposits. Loss at 43° C. from plain glass plates could be much reduced by storing them in an atmosphere saturated with DDT vapour. It appeared, therefore, that loss of toxicity at the higher temperature was due to volatilization of DDT and not to decomposition.

Plates coated with cabbage wax, stored at 43° C. in an atmosphere saturated with DDT vapour, absorbed the vapour rapidly up to a maximum of 1·7 per cent of the weight of the wax. The plates were then toxic to *T. castaneum* crawling on them. DDT dissolved in the wax layer was found to be about as toxic as the same weight of DDT per sq. cm. in crystalline form on a glass surface. DDT dissolved in wax was found to be decomposed by short-wave ultra-violet radiation more rapidly than were DDT crystals. By irradiating deposits and then analysing them, it was shown that DDT crystals on wax surfaces, when stored for up to 14 days at 43° or 18° C., do not become dissolved in the wax to an appreciable extent, provided that the plates are stored in a ventilated container.

It is concluded that, although DDT can be taken up by a typical plant wax, this effect is unlikely to influence the toxicity of the deposit unless the DDT is able to penetrate farther than the wax layer.

133. (Thomas, W. D. E. &) Glynne Jones, G. D. (1955). The systemic properties of diethyl-S-2-(ethylthioethyl) phosphorothiolate (Demeton-S) with reference to the contamination of nectar. *Ann. appl. Biol.* **43**, 182.

The fate of diethyl S-2-(ethylthioethyl) phosphorothiolate (demeton-S) in white mustard (*Brassica alba*), borage (*Borago officinalis*) and field beans (*Vicia faba*) has been followed over several weeks using the radioactive tracer technique. Radio-assay of nectar samples from flowers which opened a few days

after spraying showed that no unchanged demeton-S, but small amounts of degradation products, were present. The highest value for total radioactivity found in the nectar corresponded to 2·7 p.p.m. expressed as demeton-S.

Radioassay of treated leaves and new growth after spraying confirmed that demeton-S is rapidly converted in the plant into two primary degradation products extractable by chloroform. Further breakdown is more rapid in new growth, and appreciable quantities of the two primary products believed to be biologically active are retained by the treated leaves.

134. KENTEN, J. (1955). The effect of photoperiod and temperature on reproduction in *Acyrthosiphon pisum* (Harris) and on the forms produced. *Bull. ent. Res.* **46**, 599.

The effect of photoperiod and temperature on the production of the various forms of *Acyrthosiphon pisum* (Harris) has been studied. In this study apterous virginoparous females were exposed throughout their lifetime to two photoperiods (8 hours/24 hours and 16 hours/24 hours) and six different temperatures. At each of the temperatures the apterae (parent aphids) received one of four treatments of photoperiod, i.e. (1) 8-hour/24-hour photoperiod throughout their whole life; (2) 8-hour/24-hour photoperiod during the period from birth until the last (imaginal) moult (nymphal period), followed by a 16-hour/24-hour photoperiod from the last (imaginal) moult until death (the adult period); (3) 16 hours/24 hours throughout life; (4) 16 hours/24 hours during the nymphal period followed by 8 hours/24 hours during the adult period. The offspring produced by the various parents were collected at successive intervals, and their form determined.

Four main forms of offspring were produced: apterous and alate virginoparae, males and oviparae. In addition, a subsidiary form of the apterous virginoparae was obtained, which had sensoria on the hind tibiae.

Sexual forms were produced at all the temperatures below 20° C., but only by those parents which received a photoperiod of 8 hours/24 hours during their nymphal period.

Parent apterae kept at temperatures of 25–26° C. and 29–30° C. that received a photoperiod of 16 hours/24 hours during their nymphal period produced no sexual forms.

The photoperiod received by parent Aphids during their adult period had no effect on the proportion of sexual offspring they produced.

Males were only produced at 19–20° C. and at 11–13° C.; the largest proportion was produced at 19–20° C., where between 20 and 30 per cent of the total offspring were males.

Females were produced at all of the temperatures below 20° C. The highest proportion were produced at 11–13° C., where between 56 and 80 per cent of the total were oviparae.

Alatae were rarely produced in large numbers. The largest proportions were produced at the lower temperatures by those parents which received a photoperiod of 16 hours/24 hours throughout their nymphal and adult periods.

Apterous virginoparae bearing sensoria on the hind tibiae were produced at all temperatures, the largest proportion being produced by parents which received a photoperiod of 8 hours/24 hours during their adult period.

Maximum reproduction occurred at 19–20° C., decreasing at higher and lower temperatures.

At high temperatures (29–30° C.) few offspring were produced. They frequently took an abnormally long time to develop, and when mature were small in size.

Length of life of the parents increased with a decrease in temperature.

LAST, F. T. & BUXTON, E. W. (1955). Photo-reactivation of *Botrytis fabae* Sardiña measured by a local-lesion technique. *Nature, Lond.* **176**, 655.

For summary see no. 113.

135. LORD, K. A. (1955). Esterase inhibition by organo-phosphorus residues, with some observations on possible effects on plant metabolism. *Ann. appl. Biol.* **43**, 192.

Organo-phosphorus residues in tissues of sprayed plants were detected by estimating the esterase-inhibiting activity of their leaf and root extracts. This method was used to examine the anti-esterase effects of mangold plants

that had been sprayed with " Systox ", parathion and " Hanane ". Extracts of leaves of these treated plants were shown to inhibit added choline esterase for some weeks after treatment. The enzymic hydrolysis of phenyl acetate by extracts of leaves and roots of mangold plants treated with these insecticides was reduced for varying periods of up to 8 weeks.

Assays of parts of bean plants that had been sprayed with demeton-S showed that anti-esterase activity was limited to those parts that had been sprayed : tissues developed subsequent to spraying showed no such effects. Leaves sprayed about 2 months previously inhibited added choline esterase and showed reduced activity in hydrolysing phenyl acetate. There is some evidence that substances, possible substrates in the plant enzyme systems affected, accumulate in treated leaves.

136. McIntosh, A. H. (1955). Particle size of insecticidal suspensions and their contact toxicity. V. Effect of physical properties on toxicity of compounds in the DDT group. *Ann. appl. Biol.* **43**, 161.

With each of nine DDT analogues, two types of simple aqueous suspension were made, one containing crystals of uniform size and the other containing colloidal particles. The toxicities of each pair of suspensions were compared by a dipping method on adult *Oryzaephilus surinamensis* L., kept at 11° C. for 24 hours after treatment. The colloid was always as toxic as the crystals, or more toxic. This difference in toxicity varied from one analogue to another. It was related to the physical properties of the analogue in the following way.

Dipping applies poison to the insects ; the amounts retained could usually be found by extraction and micro-analysis. Retention of poison from colloidal suspension was about the same for each analogue ; but crystals were retained either more or less efficiently than colloid, depending on their size and shape. Poorest retention was found with plate-like crystals of about 25 μ.

The true ratio of toxicities for each analogue (colloid : crystals) was found by correcting the observed ratio for differences in retention ; but even then there were still big differences amongst the ratios given by the different analogues.

The true ratio was taken as a measure of the difference in speed of action between the two forms of poison. If the compound could kill *O. surinamensis* by fumigant action alone, the true ratio was very small. Otherwise, it seemed to depend on two physical properties related to the process of solution of poison in the wax of the insect cuticle. They were both measured in *in vitro* tests. The film made by evaporating a drop of colloidal suspension on glass is at first globular, but it may sooner or later crystallize. The film made by evaporating a drop of a suspension of crystals can be dissolved in olive oil. If the film of crystals brought about saturation of olive oil slowly and if, in addition, the deposit from colloid crystallized slowly, the true ratio was large. Unless the analogue had both of these properties the true ratio was small. If the analogue had one or other of the properties the true ratio could be increased either by increasing the crystal size or by decreasing the rate of crystallization.

Physical properties of this sort may often affect the results of tests of insecticides, and should be taken into account when the toxicities of different compounds are compared.

There seems to be no relation between lipoid-solubility and toxicity of compounds in the DDT group. Rate of solution is probably more important.

137. Potter, C., Healy, M. J. R. & Raw, F. (1956). Studies on the chemical control of wireworms (*Agriotes* spp.). I. The direct and residual effects of BHC, DDT, D-D and ethylene dibromide. *Bull. ent. Res.* **46**, 913.

Following crop failures due to wireworm (*Agriotes* spp.) attack on Little Hoos Field, Rothamsted, two experiments were made on the use of four chemicals to prevent wireworm attack on wheat. The chemicals used were BHC, technical DDT, ethylene dibromide and D-D.

Benzene hexachloride in the form of a dust containing 3·5 per cent crude BHC was broadcast at the rate of 7·9 lb./acre crude BHC ≡ 15·2–16·0 oz. γ-isomer per acre and was combine-drilled with the seed at rates ranging from 0·98–3·92 lb./acre crude BHC ≡ 1·9–8·0 oz. γ-isomer per acre. It was also

applied as a seed dressing at the rate of 2 oz./bushel of a dressing containing 20 per cent technical γ-isomer of BHC. DDT was drilled with the seed at 7·2 lb./acre technical DDT, and ethylene dibromide and D-D were injected into the soil as soil fumigants by means of a special machine at 45·5 lb./acre and 210 lb./acre respectively.

All these treatments gave a marked increase in yield over the control plots in the season following treatment (1947–48). The highest yields were given by the plots treated with ethylene dibromide (32·1 cwt./acre) and BHC broadcast (30·6 cwt./acre) and the lowest by the DDT treatment (20·7 cwt./acre), the corresponding untreated plots producing only 8·9 cwt./acre.

In the following year the plots were sown without further treatment, with the exception of some plots in the second experiment, which were sown with seed dressed with high γ-isomer BHC and one block of nine plots which was set aside for testing for possible taint with BHC treatments.

When judged on their residual effects as indicated by crop yields, plant counts and wireworm populations, BHC broadcast and combine-drilled and the plots combine-drilled with DDT gave the best results. The two soil fumigants were not so effective, and there was no evidence that the BHC seed dressing had any beneficial residual effect.

Taste tests for possible tainting effects in the 1948–49 season, using lettuces, carrots, beetroot and potatoes, indicated that BHC applied to the soil at rates of 1·96 lb./acre and upwards may taint root crops, at least in the second year after treatment. The results are discussed in the light of other work on this subject.

138. Tattersfield, F. & Kerridge, J. R. (1955). The effect of repeated spraying of insects on their resistance to insecticides. III. Conditioning by the administration of sublethal concentrations. *Ann. appl. Biol.* **43**, 630.

The administration of carbon dioxide in sublethal concentrations or for sublethal periods of time gave rise to an increased resistance to its effect in a strain of *Drosophila melanogaster* susceptible to the toxic effects of this gas. The effect did not appear to be permanent.

The successive administration by spraying of sublethal concentrations of DDT and BHC did not increase the resistance of a strain of *D. melanogaster* to their effects, either in the insects sprayed or their progeny. Only when the dosages were such as to give a high death-rate did a significant increase of resistance of the progeny of the treated insects take place; the tendency was, if anything, to increase susceptibility, although the indications were not in favour of DDT acting as a cumulative poison.

In a preliminary series of tests the topical application of DDT in sublethal doses to the adult insects resulted in a reduction in the amount or in the rate of egg laying.

139. Ward, J. & Burt, P. E. (1956). The persistence and fate of DDT on foliage. II. Comparative rates of loss of DDT deposits from glass plates and growing leaves. *Bull. ent. Res.* **46**, 849.

A method is described of applying even deposits of insecticide to leaves without detaching the leaves from the plants. The insecticide is sprayed by hand from an air-operated paint-spray gun under controlled conditions. Using this method for applying the insecticide, the persistence of DDT on living leaves and on glass plates was investigated.

The DDT content of the deposits was estimated chemically by the Schechter–Haller method of analysis, and the toxicity of the deposits was measured by allowing adult *Tribolium castaneum* (Hbst.), confined within glass collars, to crawl on the surfaces to be tested. The deposits were found to be more toxic on leaves than on plates. This difference was shown to be due in part to the greater humidity of the environment during exposure of the test insects to deposits on leaves, as a similar enhancement of toxicity occurred when, during exposure of insects to deposits on glass or Cellophane, the humidity was kept at a higher level than usual.

The rate of loss of toxicity and of DDT when deposits were exposed to sunlight in a greenhouse for varying periods within two different ranges of air temperature was studied. The deposits were derived either from emulsions or crystalline suspensions. At the lower range of air temperatures (10°–

21° C.) there was a loss, after 37 days, of about one-third of the DDT from suspension-deposits applied at the rate of 2 μg./sq. cm. to either leaves or plates. For deposits on leaves, the losses of DDT indicated by bioassay were about equal to those found by analysis, but for deposits on plates the toxicity after exposure was markedly greater than was to be expected from the amount of DDT remaining. In another experiment within the same temperature range, but with lower rates of deposit, loss of DDT occurred more rapidly, the lower the rate of deposit, the greater being the percentage of DDT lost. Deposits from DDT emulsions included in this experiment behaved similarly to suspension-deposits.

Suspensions were used only with the higher range of air temperatures (15–30° C.), at deposit rates of 2–8 μg./sq. cm. Deposits were lost more rapidly from plates laid on a greenhouse bench than from living leaves, probably because the plates, as a result of insolation, were at a higher average temperature. Again, the lower the rate of deposit the greater was the percentage lost, and the biological activity of the exposed plates, but not the leaves, was greater than was to be expected from the amount of DDT remaining.

It is concluded that the main cause of loss of *p* : *p'*-DDT from crystalline deposits of the pure material exposed to sunlight in a greenhouse is the volatility of the DDT. Since the lower the rate at which the DDT is applied, the greater is the percentage lost in a given time, it is suggested that where maximum persistence of an insecticide is required, and conditions favour loss by evaporation, the insecticide should be applied at the maximum rate practicable.

Loss of toxicity resulting from penetration of DDT into the leaf was too small to be of practical importance.

Entomology Department

140. Banks, C. J. (1955). An ecological study of Coccinellidae (Col.) associated with *Aphis fabae* Scop. on *Vicia faba*. *Bull. ent. Res.* **46**, 561.

141. Banks, C. J. (1955). The use of radioactive tantalum in studies of the behaviour of small crawling insects on plants. *Brit. J. anim. Behav.* **3**, 158.

142. Barnes, H. F. (1955). Gall midges reared from acorns and acorn-cups. *Ent. mon. Mag.* **91**, 86.

A *Contarinia* sp., a *Dasyneura* sp., an inquiline *Clinodiplosis* sp. and a predatory *Lestodiplosis* sp.

143. (Aitkenhead, P.), Barnes, H. F. & Heath, G. W. (1955). Soil sampling for wheat blossom midges. *Plant Path.* **4**, 143.

The difficulty of identifying gall midge larvae makes the rearing of midges from the larvae obtained in soil samples highly desirable.

144. Barnes, H. F. (1955). Avoiding wheat blossom midge attacks. *Plant Path.* **4**, 147.

Shelter from sun and wind afforded by trees and hedgerows and the use of impure seed increase the chances of heavy infestations.

145. Haine, F. (1955). Beobachtungen über das Flugstartverhalten und die Dauer der Flugfähigheit der Männchen von *Periphyllus aceris acericola* Wek. *Anz. Schädlingsk.* **28**, 67.

Males were prevented from flying by winds of 3–5 m.p.h. *P. aceris acericola* maintains capacity to fly for at least 22 days.

146. Haine, E. (1954). Studien und Experimente zur Frage des Populations—und Massenwechsels und des Flugverhaltens virusübertragender Blattläuse. *Anz. Schädlingsk.* **27**, 55.

147. Haine, E. (1955). Aphid take-off in controlled windspeeds. *Nature, Lond.* **175**, 474.

A. fabae and *B. brassicae* can take off in winds up to 6–7 m.p.h. Many tree aphids take off only in lower wind speeds of 3–5 m.p.h., and some of these species, unlike those whose flight muscles autolyse, maintain ability to fly for 2–6 weeks.

148. Haine, E. (1955). The activity of the sycamore aphid, *Drepanosiphon platanoides* Schr. (Hemiptera, Aphididae). *J. anim. Ecol.* **24**, 388.

Take-off and alighting behaviour are described. *D. platanoides* maintains ability to fly for some weeks.

149. Haine, E. (1955). Biologisch-ökologische Studien an *Rhopalosiphoninus latysiphon* D. Bonn: Bundesministerium f. Ernährung, Landwirtschaft & Forsten. (*Landw.-angew. Wiss.*)

150. Johnson, C. G. & Taylor, L. R. (1955). The measurement of insect density in the air. *Lab. Pract.* **4**, 187, 235.

An account of the main problems of aerial density measurement and the design and routine operation of suction traps.

151. Johnson, C. G., Southwood, T. R. E. & Entwistle, H. (1955). A method for sampling arthropods and molluscs from herbage by suction. *Nature, Lond.* **176**, 559.

152. Long, D. B. (1955). Observations on sub-social behaviour in two species of lepidopterous larvae, *Pieris brassicae* L. and *Plusia gamma* L. *Trans. R. ent. Soc. Lond.* **106**, 421.

Aggregations of the larvae of *P. brassicae* are assisted in their formation and maintenance by the guiding effect of silk trails spun by the larvae. With *P. gamma* aggregation depended on chance larval contacts resulting from similar larval preferences of situation. A sense of larval contact was found to be of prime importance in both species. In *P. brassicae* it was responsible for the establishment of mass feeding rhythms, whilst in *P. gamma* it not only led to aggregation but was also responsible for the production of darker larvae, needing only two or three larvae in association to produce this effect.

153. Murphy, P. W. (1955). Ecology of the fauna of forest soils. *Soil Zoology. Proc. Univ. Nott. 2nd Easter School in Agric. Sci.*, 1955, 99.

154. Murphy, P. W. (1955). Note on processes used in sampling, extraction and assessment of the meiofauna of heathland. *Soil Zoology. Proc. Univ. Nott. 2nd Easter School in Agric. Sci.*, 1955, 338.

155. Murphy, P. W. (1955). Soil faunal investigations. *For. Comm. Rep. on For. Res., 1953–54*, 60.
Potter, C., Healy, M. J. R. & Raw, F. (1956). Studies on the chemical control of wireworms (*Agriotes* spp.). I. The direct and residual effects of BHC, DDT, and ethylene dibromide. *Bull. ent. Res.* **46**, 913.

For summary see no. 137.

156. Raw, F. (1955). The effect of soil conditions on Wheat Bulb Fly oviposition. *Plant Path.* **4**, 114.

In a factorial experiment designed to investigate the effects of soil conditions on oviposition, more eggs were laid on plots having a rough tilth than on those having a smooth tilth. More eggs were also laid on plots which were cultivated regularly during the oviposition period. Manuring of the plots had no effect on oviposition.

157. Raw, F. (1955). A Flotation Extraction Process for Soil Micro-Arthropods. *Soil Zoology. Proc. Univ. Nott. 2nd Easter School in Agric. Sci.*, 341.

Earlier wet sieving and flotation methods of extracting arthropods from the soil are reviewed, and a modified technique suitable for micro-arthropods is described. This involves chemical dispersion of the soil, wet sieving, flotation in concentrated magnesium sulphate solution and separation of arthropods from plant material in a plug of frozen benzene.

158. Southwood, T. R. E. (1955). The egg and first instar larva of *Empicoris vagabondus* (L.) (Hem., Reduviidae). *Ent. mon. Mag.* **91**, 96.

A description of the previously unknown egg and first larval stage of this Assassin Bug.

159. Southwood, T. R. E. The nomenclature and life-cycle of the European Tarnished Plant Bug, *Lygus rugulipennis* Poppius (*Hem., Miridae*). *Bull. ent. Res.* **46**, 845.

Recent taxonomic studies have recognized that *Lygus pratensis* (L.) consists of several species, and other workers have shown that the Tarnished Plant Bug of North America is *L. lineolaris* (P. de B.), a species confined to that continent. Although it is impossible to be certain what species is referred to in all of the earlier works on biology and pest incidence of *L. pratensis* in the Palaearctic region, evidence is given which shows that *L. rugulipennis* Popp. is the more important pest in this region, and it is to this species that the name European Tarnished Plant Bug should be applied. Observations on the life-cycle of *L. rugulipennis* in England have been carried out, and they show that there are normally two generations per year; the second generation becomes adult in the autumn and overwinters in this stage, egg-laying occurring the following spring. This agrees in general with that previously described for *L. pratensis, sens. lat.*

160. (Carvalho, J. C. M.) & Southwood, T. R. E. (1955). Revisão do complexo *Cyrtorhinus* Fieber-*Mecomma* Fieber (Hemiptera–Heteroptera, Miridae), *Bol. Mus. Goeldi*, **11**, 72 + 25 pages of plates.

The Mirid bugs of this complex are of both economic and taxonomic interest; for not only are they important in the biological control of leaf hoppers, especially in the Pacific Islands, but taxonomically they are in a confused state. Keys are given to genera and species, which are mostly redescribed and figured. Two new species of *Tytthus* and three of *Mecomma* are described.

161. Stokes, B. M. (1955). Host plants of wheat bulb fly. *Plant Path.* **4**, 102.

For the first time *Agrostis tenuis, Festuca pratensis, Hordeum murinum, Poa pratensis, Aegilops ovata, Triticum dicoccoides, T. dicoccum* and *T. turgidum* are shown experimentally to be host plants of the wheat bulb fly.

162. Stokes, B. M. (1955). Behaviour as a means of identifying two closely-allied species of gall-midges. *Brit. J. Anim. Behav.* **3**, 154.

Two gall midge species, *Dasyneura violae* and *D. affinis*, which are indistinguishable morphologically, are found to be quite distinct in their host-plant ranges (see p. 132).

163. Taylor, L. R. (1955). A tilting micromanometer with continuous sensitivity control. *J. Sci. Instr.* **32**, 173.

A null-reading liquid manometer reads air-speeds of 7·5 feet/second with a Pitot static tube. Sensitivity is highest at zero reading. The highest limits of accuracy assessed were ± 0·2 dyn/sq. cm., i.e., 6·5 feet/second ± 0·5 per cent. The upper reading limit is about 0·7 inches W.G. (50 feet/second).

Bee Department

General Papers

164. Butler, C. G. (1955). The rôle of "queen substance" in the social organization of a honeybee community. *Amer. Bee J.* **95**, 275.

165. Butler, C. G. (1955). Pest control—without killing the bees. *Agric. Rev., Lond.* **1**, 54.

166. Ribbands, C. R. (1955). The scent language of honeybees. *Discovery*, **16**, 22; (to be reprinted in Smithsonian Inst. Ann. Rep. for 1955.)

167. Ribbands, C. R. (1955). The honeybee. *Sci. Amer.* **193**, 52.

168. Ribbands, C. R. (1955). Bee scents. *Brit. Bee J.* **88**, 96.

169. Ribbands, C. R. (1955). The origin of bee scents. *Brit. Bee J.* **88**, 328.

170. Ribbands, C. R. (1955). Community defence against robber bees. *Brit. Bee J.* **88**, 380.

171. Ribbands, C. R. (1955). Autumn feeding. *Brit. Bee J.* **88**, 432.

172. Ribbands, C. R. (1955). What can a honeybee smell? *Brit. Bee J.* **88**, 600.

(The last five articles were also printed in other national bee journals.)

Research Papers

173. Bailey, L. (1955). Trials with Acaricides at Rothamsted. *Bee World*, **36**, 14.

This short note gives some results of initial experiments with acaricides applied as smokes. The results of continental workers are confirmed, and the apparent superiority of *p*-chlorophenyl, *p*-chlorobenzene sulphonate as an ovicide is noted.

174. Bailey, L. (1955). Control of Amoeba Disease by the fumigation of combs and by fumagillin. *Bee World*, **36**, 162.

The sterilization of combs contaminated with cysts of *Malpighamoeba mellifica* was shown to be possible when acetic acid was used in the way previously described for combs contaminated with Nosema spores.

Fumagillin did not appear to have the striking effect upon an established Amoeba infection as it has upon an infection with Nosema.

175. Bailey, L. (1955). The infection of the ventriculus of the adult honeybee by *Nosema apis* (Zander). *Parasitology*, **45**, 86.

Spores of *Nosema apis* nearly all germinate within 30 minutes of entering the ventriculus, the anterior end of which receives the heaviest initial infection. It is suggested that the parasite is injected into the ventricular cells from the spore via the hollow polar filament.

The central region of the ventriculus receives the lowest initial infection and it seems likely that suppression of infection is linked with the higher concentration of intracellular granules of calcium phosphate found in this region.

176. Bailey, L. (1955). Results of field trials at Rothamsted of control methods for Nosema disease. *Bee World*, **36**, 121.

Erratic results were obtained with fumagillin when fed in syrup in the autumn, and in one trial doses up to 500 mgm. per colony had no significant effect upon the development of the disease during the following spring. Striking success was achieved after colonies had been transferred to combs which had been sterilized with the vapour of acetic acid or of formaldehyde.

177. Bailey, L. (1955). The epidemiology and control of Nosema disease of the honeybee. *Ann. appl. Biol.* **43**, 379.

The work done at Rothamsted since 1952 upon this disease is summarized and the experiments leading to the practical methods of control previously reported are described.

178. Butler, C. G. (1955). Some recent advances in apicultural research. *Annu. Rev. Ent.* **1**, 281.

A critical review of recent research work on certain aspects of bee behaviour and physiology, including: effects of anaesthetics on adult bees; colony odour; clustering; laying workers; control of queen production; caste determination; division of labour. 108 references are cited.

179. Butler, C. G. (1956). Some further observations on the nature of "queen substance" and of its rôle in the organization of a honeybee (*Apis mellifera*) community. *Proc. R. ent. Soc. Lond.* (A) **31**. (In the press.)

Further evidence is given in support of the view that both queen production and the normal inhibition of development of a worker's ovaries are controlled by queen substance; effective extracts of which have now been obtained in a number of organic solvents. It is demonstrated that one way in which this substance is widely distributed amongst the adult members of a colony, after being licked from the queen's body by a few bees, is in regurgitated food. It is also pointed out that queen substance may act indirectly, rather than directly, upon a recipient bee causing the release of a hormone which affects this bee's metabolism.

180. (Carlisle, D. B.) and Butler, C. G. (1955). The "queen substance" of honeybees and the ovary-inhibiting hormone of crustaceans. *Nature, Lond.* **176**, 276.

It has been shown that extracts of honeybee "queen substance" can inhibit ovary development in prawns (*Leander serratus*) whose eyestalks have been removed, and that similar extracts from the sinus glands of female prawns can inhibit ovary development in worker honeybees. It is suggested that a common ovary-inhibiting substance occurs in Arthropoda.

181. Free, J. B. (1955). Queen production in colonies of bumblebees. *Proc. R. ent. Soc. Lond.* (A), **30**, 19.

Queen bumblebees were induced to found colonies in captivity by confining them with varying numbers of workers and abundant food. When sufficient workers were present to help the queen some of the first eggs she laid gave rise to queens. The factors leading to the production of queens in wild colonies are discussed.

182. Free, J. B. (1955). The adaptability of bumblebees to a change in the location of their nest. *Brit. J. Anim. Behav.* **3**, 61.

Most of the foragers of a bumblebee colony returned successfully to their nest when it was moved to a new position outside their foraging range. However, if the new site was within their foraging range a high proportion of foragers returned to it, but most of them, at the end of their first foraging trips from the new site, returned to the old site before proceeding to the new one. Their subsequent behaviour varied according to the distance between the old and new sites. Individuals differed greatly in their learning abilities.

183. Free, J. B. (1955). The division of labour within bumblebee colonies. *Insectes soc.* **2**, 193.

The majority of the workers of a bumblebee colony were found to be either consistent foragers or house-bees, but many performed either task in accordance with the current requirements of their colony. The longer a worker had undertaken household or foraging duties, the more "fixed" she became to the duty concerned.

Foragers showed great constancy to the collection of either pollen loads or nectar loads during consecutive trips, but showed little constancy for

periods of a day or more. The type of food collected was determined to some extent by colony requirements, which depend on the nature and amount of the food stores possessed by a colony and on the age of its brood.

184. FREE, J. B. (1955). The behaviour of egg-laying workers of bumblebee colonies. *Brit. J. Anim. Behav.* **3**, 147.

A social order, based on dominance, was found to exist in bumblebee colonies. In bumblebee colonies deprived of their queens, and in colonies started by workers alone, animosity occurred between the workers. In each colony one of the workers became the dominant and attacked any of the other workers, although as many as three workers in one colony were seen to attack other bees. The number of attacks was greatest at the time that the social order was established, and thereafter declined. In the majority of colonies the dominant bee had the most developed ovaries, and the bee she attacked most tended to have the next most developed ovaries. The results are discussed in relation to the evolutionary development of bee colonies.

185. FREE, J. B. & BUTLER, C. G. (1955). An analysis of the factors involved in the formation of a cluster of honeybees (*Apis mellifera*). *Behaviour*, **7**, 304.

Individual bees are attracted to a cluster of bees by the stimuli of scent, heat and vibration, which the bees of the cluster produce. Each of these stimuli, provided it is of sufficient magnitude, is by itself sufficient to attract individual bees to join the cluster. Bees are also attracted by the sight alone of actively moving bees. Hungry bees normally prefer to join a cluster of bees from whom they can obtain food, but groups of well-fed bees are more attractive to individual bees than are groups of starving bees, probably because of their greater activity, even when the individual bees are unable to obtain food from them.

186. RIBBANDS, C. R. (1954). Communication between honeybees. I. The response of crop-attached bees to the scent of their crop. *Proc. R. ent. Soc. Lond.* (A), **29**, 141.

Bees from one colony were trained to forage, in equal numbers, from two Petri dishes 50 yards apart. One dish was supplied with sugar syrup scented with benzyl acetate, the other with sugar syrup scented with methyl benzoate. Training took place after 14.00 hours G.M.T. only, but when the bees had been sufficiently time-conditioned the dishes were put down in the morning. One or other of the two scents was then pipetted into the hive; the addition of the scent to which it had been trained doubled the chance that the bee would visit the feeding-place outside the usual training time. Thus the mere presence of the training scent in the hive, in the absence of either food sharing or dancing, can encourage bees to go to a crop to which they are accustomed.

187. RIBBANDS, C. R. (1955). Communication between honeybees. II. The recruitment of trained bees, and their response to improvement of the crop. *Proc. R. ent. Soc. Lond.* (A), **30**, 26.

Equal numbers of individually marked bees from one colony were trained to forage from each of three Petri dishes placed in different directions from the colony. Dilute sugar syrup was supplied at first, and then replaced by concentrated syrup. The dish at which the supply improved then attracted twice as many recruits as did the dish at which concentrated syrup was always available.

Although the three dishes were only 50–72 yards from the hive, the trained bees were separately recruited to them. Previously trained bees recruited on their first return to the hive, and exposed their scent organs during their second visit to the food source. Individual differences in the behaviour were impressive. The implications of these results are discussed.

188. RIBBANDS, C. R. (1955). The scent perception of the honeybee. *Proc. Roy. Soc.* B, **143**, 367.

By a new technique it has been shown that honeybees can perceive pure chemical scents in great dilution, and that they can distinguish between mixtures which contain only slightly different proportions of the same two scents.

A honeybee was attracted to the body scent which it left behind some time previously on a glass tube on which it had landed momentarily *without* exposing its scent organ; this body scent may often aid bees in their foraging activities.

Amputation of seven terminal segments of both antennae greatly impaired the threshold of scent perception.

The scent perception of the honeybee is compared with that of other insects, and the problems which have not yet been solved are emphasized.

189. Simpson, J. (1955). The significance of the presence of pollen in the food of worker larvae of the honeybee. *Quart. J. micr. Sci.* **96**, 117.

It is shown that worker larvae receive a variable quantity of pollen in their food in summer and sometimes none at all in winter. This pollen probably supplies less than one-tenth of the nitrogen requirements of the growing larvae.

Statistics Department

Research Papers

190. Boyd, D. A. & Lessells, W. J. (1955). Seed-setting for higher profits. *Agric. Rev. Lond.* **1**, 53.

The effect of seed-rate on the yield of potatoes is discussed.

191. Church, B. M. (1955). Weedkillers and insecticides applied to cereals and peas, swedes and kale. *Plant Path.* **4**, 131.

Data from fertilizer surveys carried out in 1954 show that in arable farming districts of Eastern England between a quarter and a half of the cereal acreage was treated with weed-killers. In surveyed districts having less than a third of their acreage in tillage crops, only 10 per cent of the cereals were treated. Formulations of MCPA were used on about 80 per cent of treated fields, the remainder receiving 2, 4-D or DNC weed-killers.

The extent to which various formulations of DNBP were used as weed-killers on peas varied greatly between districts. DDT insecticides were applied to 10–20 per cent of the pea acreage in most areas. In only one district amongst those surveyed was a large part of the kale acreage sprayed or dusted with DDT or BHC insecticides against flea beetle.

192. Church, B. M. (1956). Cereal manuring in England and Wales. *J. Sci. Fd Agric.* (In the press.)

Information on the manuring of cereals obtained from fertilizer practice surveys (1950–54) is presented, and estimates of optimum fertilizer dressings are given for comparison with present practice. Regional differences in manuring, and the influence of previous cropping, the varieties grown, and methods of fertilizer application are considered.

More than a third of the cereal acreage in England and Wales received no nitrogen fertilizers, and the average dressings given were 0·25–0·35 cwt. N/acre compared with a calculated optimum dressing of 0·6 cwt. N/acre. On the available experimental evidence, average potash dressings were about optimal but phosphate fertilizers were used on much of the cereal acreage at rates above the optimum. A third of the nitrogen used on winter cereals was applied in the seedbed in autumn. Due to use of complete fertilizers as top dressings, a sixth of the phosphate and a quarter of the potash used on winter cereals were applied in spring top dressings. About half the phosphate and potash fertilizers used in the seedbed were combine drilled. Profitable increases in the use of nitrogen on that part of the cereal acreage which receives little or no nitrogen would increase the total cereal yields of England and Wales by about 6 per cent.

193. Church, B. M. & Lipton, S. (1956). Use of an electronic computer in the estimation of sampling errors in a nutritional survey. *Brit. J. Nutr.* **10**, 27.

The empirical evaluation of sampling errors of all kinds has in the past been greatly neglected due to the laborious calculations required on desk machines. With the development of electronic methods these computations can now be readily undertaken. The paper describes a method of evaluating the sampling

errors of a numerical sequence using the electronic computer installed at Rothamsted. The method was developed to deal with the data of a nutritional survey, but the programme has been written in general form and can take account of missing values.

194. Church, B. M., Westmacott, M. H. & (Jacob, F. H.) (1955). A survey of rabbit damage to winter cereals, 1953–54. *Plant Path.* (In the press.)

A country-wide survey of rabbit damage to winter wheat was first carried out in 1951–52. This paper describes a further survey of winter cereals in England and Wales undertaken in 1953–54 to obtain estimates of damage for another year and to extend the results of the previous work. Although myxomatosis was spreading through the country at the time of the survey, it clearly had a negligible effect on the results.

The estimated loss in 1953–54 due to rabbit damage on winter-sown cereals in England and Wales was 1·4 cwt. grain/acre, compared with 1·6 cwt./acre for winter wheat in South and Central England in 1951–52. About a third of the winter-cereal acreage was moderately or severely grazed by rabbits, and the surveyors judged that on over half of this acreage the farmers had no organized policy for rabbit control.

195. (Ellison, W.), Boyd, D. A. & Church, B. M. (1955). The progress of improvement on upland and hill farms in England and Wales: some results of a recent survey. *J. R. agric. Soc.* **116**, 34.

The results are described of a survey of upland and hill farms undertaken at the request of the Agricultural Research Council and the Ministry of Agriculture in 1953–54. The field work was carried out in Wales and in Northern and South-West England by members of the National Agricultural Advisory Service and the Agricultural Land Service in the provinces concerned. The main objects of the survey were to provide estimates of: (i) the returns from public and private expenditure incurred under the Hill Farming and Livestock Rearing Acts, and (ii) the scope for further improvements on farms eligible for assistance under the Acts.

Farms on about 40 per cent of an estimated total of 4½ million acres on eligible farms in England and Wales had undertaken improvements under the Acts by 1953. The estimated total cost of work approved was £11 million; of this sum about two-thirds was for improvements to farmhouses, cottages, buildings, roads and services, the remainder being for land improvements. Since less than half the approved work had been done, and much had only been recently completed, the full effects on the farm economy could not be measured, but the survey provides a base-line for a more complete assessment at a later date. The surveyors recommended additional improvements at a total cost of £5·6 million on farms with schemes, and improvements on other eligible farms costing £25 million. Factors restricting the improvements likely to be undertaken are discussed.

Owing to lack of accurate information on output in years preceding the survey, provisional estimates of changes in output were derived from assessments of field stock carrying capacity and the numbers of stock on farms. It was estimated that full implementation of all work approved under the Acts might increase annual output by 26,000 two-year-old store cattle or equivalent, and work recommended by the surveyors might give a further increase of 60,000 stores. The estimated return on the total capital investment in improvements was 3–4 per cent per annum, no deduction being made for interest on capital. If grants totalling 50 per cent of the cost were paid in respect of all improvements, the corresponding return to the farmer would be 10–12 per cent of his smaller capital investment.

196. Gower, J. C. (1955). A note on the periodogram of the Beveridge Wheat Price Index. *J. R. statist. Soc. B.* **17**, 228.

The complete periodogram of the Beveridge Wheat Price Index was calculated on the Manchester University computer. The results were then used to test the goodness of fit of the second-order autoregressive scheme proposed by Sargan.

197. GRUNDY, P. M., HEALY, M. J. R. & REES, D. H. (1956). Economic choice of amount of experimentation. *J. R. statist. Soc. B.* (In the press.)

This is the detailed version of an earlier paper "Decision between two alternatives—how many experiments?" of which an abstract appeared in the 1954 report (paper no. 180).

198. HEALY, M. J. R. (1955). A significance test for the difference in efficiency between two predictors. *J. R. statist. Soc. B.* **17**, 266.

If a dependant variate y can be predicted by linear regression on either of two alternative predictors x_1 and x_2, it is natural to measure the efficiency of prediction by the smallness of the residual variance of y. Given a sample of values of y, x_1 and x_2, Hotelling has derived a method of testing whether one predictor significantly exceeds the other in efficiency. This test is derived in a simpler manner and put into a form suitable for computation.

199. HEALY, M. J. R. (1956). The analysis of a factorial experiment with additional treatments. *J. agric. Sci.* (In the press.)

It is often desirable in a factorial experiment to include certain treatments outside the main factorial scheme. The detailed analysis of an experiment of this type is discussed.

200. HEALY, M. J. R. (1956). Weighted probits allowing for a non-zero response in the controls. *Biometrika.* (In the press.)

Black has shown that standard probit calculations can be facilitated by the use of tables of weighted probits. It is shown that the effects of a non-zero response rate in untreated material can be fully allowed for by a slight modification of these tables, and it is pointed out that their use is convenient on automatic high-speed computers.

201. HEALY, M. J. R. & WESTMACOTT, M. H. (1956). The problem of missing values in experiments analysed on automatic computers. *Appl. Statist.* (In the press.)

This article describes a method of handling experimental data with missing values that is sufficiently general to be used in conjunction with any programme for analysing experimental data, and is at the same time simple and satisfactorily fast. The method carries out the calculation of the fictitious values needed to enable the experiment to be analysed in the ordinary way. The calculation is iterative and starts from guessed values for the missing data; at each stage the residual of each missing unit (calculated by the main programme) is subtracted from the value ascribed to that unit at the beginning of the cycle. The process is shown to converge to the required values.

202. HODNETT, G. E. (1956). The responses of sugarcane to fertilizers. *Emp. J. exp. Agric.* (In the press.)

Average standardized responses of plant-canes and ratoons to nitrogen, phosphate and potash were estimated from the results of over 1,000 experiments conducted in British Colonial and Commonwealth Territories since about 1930. The responses (in terms of sugar) were examined in relation to ecological regions within each territory. Responses to organic manure, by-products and lime were also summarized.

Nitrogen responses were observed everywhere. Under irrigation they were usually larger, while the ratoons generally responded more than the plant-canes. No residual response was observed. The sugar percentage was consistently reduced. Sulphate of ammonia appears to be the most effective form of nitrogen.

With phosphate, the responses tended to be associated with soil types. They were generally rather small and similar with successive crops. The effect on the sugar percentage was small and irregular.

Responses to potash were also associated with soil types and to some extent with rainfall. The ratoons tended to give somewhat higher responses than the plant-canes.

Small, positive interactions were found between nitrogen and phosphate and between nitrogen and potash. Pen manure tended to reduce the responses to the main inorganic fertilizers. There was no evidence for interactions between fertilizers and varieties.

203. Hodnett, G. E. (1956). The use of response curves in the analysis and planning of series of experiments with fertilizers. *Emp. J. exp. Agric.* (In the press.)

The estimation of the parameter k for average response curves of exponential form is briefly discussed. Various methods of estimating standard responses are examined. The efficiencies of experiments of fixed size using different numbers of levels are compared, and considerations affecting the choice of levels are discussed. The importance of the zero level is demonstrated.

204. Hodnett, G. E. (1956). The analysis of a 3×6 experiment arranged in a quasi-Latin square. *Biometrics.* (In the press.)

The analysis of a 3×6 factorial experiment arranged in a 6×6 quasi-Latin square is described, and details are given of a general method for computing the standard errors of comparisons between treatment means adjusted for confounding. The application of this method to the computation of standard errors of treatment comparisons in split-plot designs is indicated.

205. (Le Couteur, K. J.) & Lipton, S. (1955). Non-linear regenerative extraction of synchrocyclotron beams. *Phil. Mag.* **46**, 1265.

To extract a beam of maximum energy from a synchrocyclotron the deflector must be placed at the edge of the magnet, where the magnetic field falls off rapidly and non-linearly with radius. This presents an analytical problem of coupled non-linear differential equations with periodic coefficients. The computer at Rothamsted was used to provide solutions, and it was concluded that a non-linear deflector can extract the beam with higher energy than the linear one at Liverpool. These proposals were primarily intended for the Liverpool and C.E.R.N. synchrocyclotrons, but are being applied to several others. The expected results have already been obtained in Chicago.

206. Leech, F. B. (1955). Vital statistics in the study of cattle disease. *Agric. Progr.* (In the press.)

Vital statistics may be collected on the farm for the following reasons :

(1) Economic studies in which attention may be focused either on cattle as a source of income or on the losses that result from animal disease.
(2) For studies of the ecology of disease.
(3) To estimate the efficacy of methods of preventing or controlling disease.

Methods appropriate to the particular type of study are discussed in general terms. Various types of survey can provide data suitable for the first two types of study. The third requires field experiments, often on a large scale; problems in the planning and interpretation of these are mentioned.

207. Leech, F. B. (1955). Contribution to discussion of papers on vital statistics. *Vet. Rec.* (In the press.)

A correct estimate of the incidence of certain diseases is virtually unobtainable, and some of the reasons for this were discussed. It was also pointed out that disease incidence should generally be reported under two headings—percentage of farms affected and the percentage of affected cows on affected farms.

208. Lipton, S. (1955). A note on the electronic computer at Rothamsted. *Math. Tab., Wash.* **9**, 69.

A short description of the computer is given, together with a few examples of problems that have been solved.

209. Patterson, H. D. (1956). A simple method for fitting an asymptotic regression curve. *Biometrics.* (In the press.)

Simple methods for fitting the regression equation

$$y = \alpha - \beta\rho^x, \text{ where } 0 < \rho < 1$$

are suggested for cases in which the ordinates x are equally spaced and take 4, 5, 6 or 7 values.

The estimates of ρ are given by the ratios of two contrasts between the

values of y. These contrasts are chosen so that the efficiencies of the proposed estimates are high over the range of useful values of ρ.

Once ρ has been estimated α and β can be determined by a straightforward linear regression.

Potter, C., Healy, M. J. R. & Raw, F. (1956). Studies on the chemical control of wireworms (*Agriotes* spp.). I. The direct and residual effects of BHC, DDT, D -D, and ethylene dibromide. *Bull. ent. Res.* **46**, 913.

For summary see no. 137.

210. (Rollinson, D. H. L., Harker, K. W., Taylor, J. L.) & Leech, F. B. (1956). Studies in the habits of Zebu cattle. III. Errors associated with recording technique. *J. agric. Sci.* **47**, 1.

To obtain records of individual animals' habits when a small herd is observed for long periods of time, several observers are essential. The errors between observers were so much less than those between animals and between periods of observation that for most purposes records made by a succession of different observers will be adequate.

The errors of observations at 1-minute and 4-minute intervals, using the grazing records of ten animals, were 3·20 and 7·36 per cent of the mean respectively. The latter figure being of sufficient accuracy for practical application, it is concluded that the 4-minute interval is suitable for records of a major habit.

The errors for the minor habits were large relative to the mean time occupied on them, but still reasonable in relation to the purposes for which work of this sort would usually be required.

211. (Tanner, J. M.), Healy, M. J. R., (Lockhart, R. D., Mackenzie, J. & Whitehouse, R. H.) (1955). Aberdeen Growth Study: I. The prediction of adult body measurements from measurements taken each year from birth to five years. *Arch. Dis. Childh.* (In the press.)

A number of children in Aberdeen were measured at each birthday from 0 to 5 years. Eighty of the same individuals have been re-measured as adults, and the paper discusses the prediction of the adult values from those taken in childhood. Among other results, it is shown that the correlation of birth measurements with adult measurements are uniformly small; also that the best age over the range studied for predicting adult values is usually 3 years old, earlier or later information adding very little to the goodness of the prediction.

212. Westmacott, M. H. & Rees, D. R. (1955). The feeding of fodder beet to pigs. *J. agric. Sci.* (In the press.)

Data from thirty-eight experiments in Denmark and Britain comparing an all-meal diet for fattening pigs with one containing fodder beet are summarized and the results discussed. The daily intake of starch equivalent, and hence the rate of growth, of pigs given fodder beet is shown to be less than that of pigs given an all-meal ration. Apart from this reduction in rate of growth, it is shown that the value of fodder beet as a food for pigs may be satisfactorily assessed using the starch equivalent system.

213. Yates, F. (1955). The use of transformations and maximum likelihood in the analysis of a set of quantal experiments involving two treatments. *Biometrika*, **42**, 382.

The analysis of sets of quantal experiments with two treatments by the use of transformations and maximum likelihood is discussed, and illustrated by examples, one of which is also treated by large-sample methods. Methods are given for (*a*) obtaining an estimate of the treatment difference in terms of the transformed variate, together with its standard error, (*b*) testing for differences in sensitivity between the different experiments, and (*c*) testing for variation in the treatment difference from experiment to experiment. The appropriateness of various transformations under different circumstances is also considered.

214. YATES, F. (1955). A note on the application of the combination of probabilities test to a set of 2 × 2 tables. *Biometrika*, **42**, 404.

It is shown that χ^2 without correction for continuity will give one-tail probabilities for 2 × 2 tables which may be safely combined in most cases likely to be met with in practice. The summation of the corresponding signed values of χ gives a rapid method of combination. Reasons are given for believing that combination of probabilities tests are not likely to be very efficient, and this conclusion is demonstrated by a small sampling experiment.

215. YATES, F. & (FINNEY, D. J.) (1955). Report to the Government of India on statistics in agricultural research. *F.A.O. report*, no. 358.

This report has its origin in a visit paid by the authors to India in 1952/3 at the request of the Government of India under the auspices of the Food and Agriculture Organization of the United Nations. The main object of the visit was to advise and assist the Indian Council of Agricultural Research in the teaching and research programme of its Statistical Branch.

The report discusses the organization of statistical assistance that can best serve the needs of the research administrative advisory services and the way in which this organization can be developed. Observations on certain aspects of field experimental work in India are also included, since statistics have much to contribute to the improvement of techniques and the utilization of the results. It is thought that many of the matters discussed in the report will be of interest not only to the various agricultural research organizations in India but also to similar organizations in many other countries.

REVIEW

216. LEECH, F. B. (1955). "British Poisonous Plants", by A. A. Forsyth. *Bull. Minist. Agric. Lond.* 161.

Woburn Experimental Station

217. MANN, H. H. (1956). Weed herbage of slightly acid arable soils as affected by manuring. *J. Ecol.* (In the press.)

The weed herbage growing about the beginning of June was investigated on a greensand soil treated for a series of eight years with large amounts of bulky organic manures, including farmyard manure, sewage sludge and several types of compost. The land was under regular cropping with two market-garden crops per year. The pH value of the soil varied from about 5·0 to about 6·5. The dominant weeds on the whole were *Urtica urens*, *Lamium amplexicaule* and *Capsella bursa-pastoris*, but in the more acid plots *Spergula arvensis* and *Matricaria* sp. were the most frequent. The two last were, however, very rapidly reduced as the acidity decreased, *Spergula* being the most numerous at pH 5·0 or below, and *Matricaria* at just over 6·0.

The effect of the various organic manures on the weed herbage was not widely different, and all increased the weediness by about 30 per cent, farmyard manures less than the other bulky manures. Certain of the weeds, such as *Poa annua*, *Matricaria* sp., *Veronica* sp. and *Chenopodium album*, seem indifferent to the presence or absence of organic manures, while others, like *Urtica urens*, are very much encouraged by farmyard manure, and *Capsella bursa-pastoris* and *Senecio vulgaris* by sewage sludge or composts containing it. Doubling the dressing of manure made little difference to the amount of weeds, except in the case of the annual nettle, where the larger amount of the organic manures produced over 77 per cent more nettle plants per unit area. The addition of sulphate of ammonia to the variously manured plots made very little difference to the weediness of the plots.

In an area where the land is ploughed at least twice a year and regularly cultivated, it seems clear that constant hoeing does not easily rid the land of weeds, and some weeds, like the annual nettles, seem to enjoy it.

218. Mann, H. H. & Barnes, T. W. (1956). The permanence of organic matter in soil. *J. agric. Sci.* (In the press.)

An experiment at Woburn in which several bulky organic manures were applied in large amounts every year from 1942 to 1950, coupled with two inter-tilled crops a year, gave the opportunity to measure the proportion of the added organic matter that remained in the soil at the end of this period. Four bulky organic manures were used, namely farmyard manure, sewage sludge and two types of compost made with straw and activated with dung or with sewage sludge respectively. They were applied each year in February at two rates, namely 15 and 30 tons of manure per acre.

Examination of the soils at the end of the 8-year period seems to justify the following conclusions. (1) The different materials divide themselves into two classes: farmyard manure in which the organic matter appears to be considerably more active than in any of the other materials used, and the other three manures, which are not widely different, though the least active is the compost made with sewage sludge. (2) Addition of sulphate of ammonia to the bulky manure slightly reduced the rapidity of disappearance of the organic matter except with the farmyard manure. (3) Doubling the amount of manure added has led to disappearance of a larger proportion of the added organic matter after 8 years, except, again, with the farmyard manure.

After 8 years only 50 per cent of the organic matter added is left in the soil when given as farmyard manure: with the other materials the amount remaining in the soil is much greater, going up to nearly 75 per cent with a straw compost made with sewage sludge.

219. Dyke, G. V. (1956). The effect of date of planting on the yield of potatoes. *J. agric. Sci.* (In the press.)

Evidence obtained in the A.I.C. Survey of Maincrop Potatoes 1948–50 and in experiments shows that yields in England and Wales are decreased by delay in planting after about 11 April, at the rate of about 0·4 tons/acre per week. The effect is rather greater in years with fine springs, and on high-yielding fields.

In Rothamsted experiments the responses to dung and fertilizer were all greatly reduced when planting was delayed; between early April and late May the effects of dung, nitrogen and phosphate were halved, while that of potash was reduced by about 80 per cent. The evidence on the responses of different varieties to early planting in English experiments is contradictory, except for an indication that higher-yielding varieties respond better. Data from Craibstone suggests that, if bulk yield is the only criterion, "early" varieties which make rapid growth early in the season have a later optimum planting date than maincrop varieties.

The effect of chitting seed at Craibstone is to increase yields by 1·7 tons/acre for March plantings, but the effect increases for plantings in April and later to 2·5 tons/acre. There is negligible loss of yield from sprouted seed at Craibstone for plantings delayed up to mid-April, but for unsprouted seed there is evidence of a gain from plantings a month earlier. Sprouted seed planted even as late as May 1 yielded as well as unsprouted planted 2 months earlier.

About half the main crop potato acreage of England and Wales in each of the years 1948–50 was planted so late as to suffer appreciable loss of yield. At least one-fifth seems likely to have lost 1 ton/acre or more from delay. The potential increase in national production if all fields were planted by 11 April is equivalent to about 0·5 tons/acre, or 5 per cent of the total production.

Field Experiments Section

220. Dyke, G. V. & Meyler, S. (1956). Indoor experiments with a combine harvester. *Exp. Husb.* (In the press.)

221. Garner, H. V. (1955). Manuring of cereal crops. *J. Inst. Corn Merch.* **5**, 12.

Soil Survey of England and Wales

222. The soils of the Glastonbury district of Somerset (Sheet 296). (1955). London: H.M. Stationery Office.

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223. Boalch, D. H. (1955). The Commonwealth Agricultural Bureaux and their contribution to world agricultural bibliography. In : *Commun. 3rd int. Congr. Libr., Brussels 1955*, vol. 2A.

224. Ogg, Sir W. G. (1955). The chemist and the farmer. Presidential address delivered at the 74th Annual General Meeting of the Society of Chemical Industry, Birmingham, 12 July 1955. *Chem. & Ind.* 928.

225. Ogg, Sir W. G. (1955). Chemistry and crop nutrition. Ninth Dalton Lecture. *Lect. Inst. Chem.* no. 5.

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Catalogue of the printed books on agriculture published between 1471 and 1840, by Mary S. Aslin. (Rothamsted, 1926.) *
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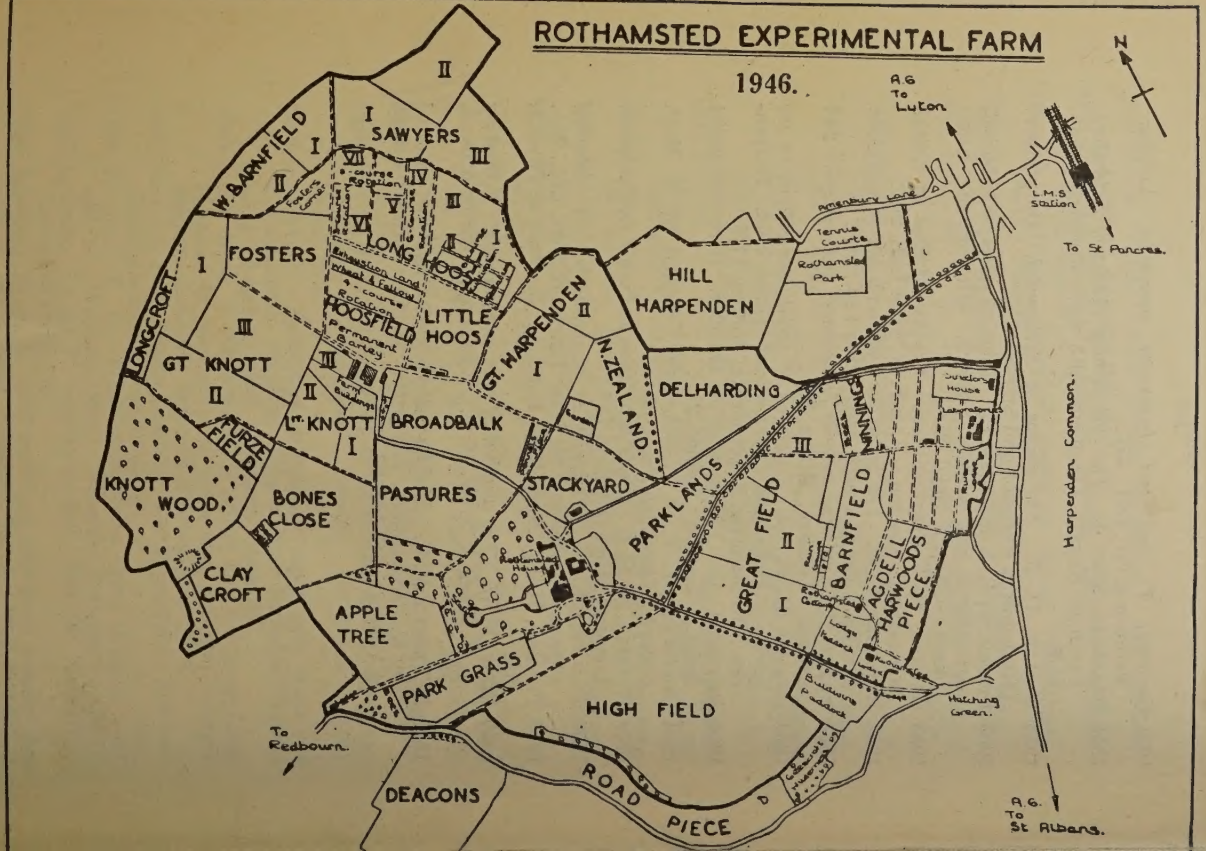

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